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BULLETIN No. 3

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Investigations of the Economical Duty of Water for Alfalfa in Sacramento Valley, California

1910-1915

(Based on data gathered under cooperative agreement between the Office of Public Roads and Rural Engineering of the United States Department of Agriculture, the California State Department of Engineering, and the University of California Agricultural Experiment Station and reprinted from the Fifth Biennial Report of the Department of Engineering.)

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Department of Engineering, State of California

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Office of Public Roads and Rural Engineering

United States Department of Agriculture

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SAMUEL FORTIER -------------- *Chief of Irrigation Investigations*

University of California

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Investigations of the Economical Duty of Water for Alfalfa in Sacramento Valley, California

1910-1915

By FRANK ADAMS, RALPH D. ROBERTSON, SAMUEL H. BECKETT, WELLS A. HUTCHINS, and O. W. ISRAELSEN, Cooperative Irrigation Investigations in California.

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CONTENTS.

ILLUSTRATIONS.

INVESTIGATIONS OF THE ECONOMICAL DUTY OF WATER FOR ALFALFA IN SACRAMENTO VALLEY, CALIFORNIA, 1910-1915.

By Frank Adams, Ralph D. Robertson, Samuel H. Beckett, Wells A. Hutchins and O. W. Israelsen,

Cooperative Irrigation Investigations in California.

INTRODUCTION.

As a part of the cooperative irrigation investigations in California conducted under agreement between the Office of Public Roads and Rural Engineering,[1] the State Department of Engineering of California, and the California Agricultural Experiment Station, a series of experiments was begun in 1910 at the University Farm, at Davis, California, which sought to determine the most economical duty of water for alfalfa in Sacramento Valley. At the end of the third year of these experiments it was decided to supplement them by investigations on a large number of representative alfalfa farms in Sacramento Valley, in order to test the applicability of the results obtained at Davis to the varying soil and rainfall conditions in other parts of the valley. These latter studies were carried through the seasons of 1913 and 1914 and were in turn supplemented during the season of 1915 by studies on a temporary experimental plat about five miles northeast of Willows. In the meantime the experiments begun at Davis in 1910 were continued through a six-year period, ending with the close of the season of 1915. It is the purpose of this report to present the results of the entire investigation.

Bearing of the Investigation.

It is now well recognized, regardless of the crop irrigated, that a proper knowledge of the duty of water is of importance to both irrigators and the public, and especially is this the case in newly developing irrigated sections such as Sacramento Valley. In this large area where dry grain farming has prevailed so long, and where field crops and live stock admittedly are the basis of the most suitable agriculture for the area as a whole, a proper understanding of the amount of irrigation water that should be applied to alfalfa is of prime necessity. The irrigator must have this information that he may make the necessary arrangement for an adequate water supply, that he may avoid injury of his soil through the application of too much water, and that he may adjust to his land the amount available to him, so as to obtain the largest possible returns per acre-foot of water applied. Further, he

[1]Prior to July 1, 1915, between the Office of Experiment Stations and the California agencies named.

must have an understanding of the underground movement of irrigation water after it is applied, that he may be sure, on the one hand, that excessive losses are not occurring through too deep percolation, and, on the other hand, that the irrigation water is penetrating the soil sufficiently deeply to give proper nourishment to the feeding roots of the plants. Especially must the farmer have information as to what becomes of the irrigation water after it leaves the surface where there is such a large percentage of "hard" soil as in Sacramento Valley—soil into which, in its present poor physical condition, it is extremely difficult to make irrigation water reach even 12 to 24 inches below the surface.

EXPERIMENTS AT THE UNIVERSITY FARM AT DAVIS.

During 1910 and 1911, a tract of 8.19 acres was utilized in the experiments at Davis, the land being in square and contour checks 0.20 to 1 acre in area and averaging 0.28 acre. The soil of these plats is classified by the Bureau of Soils and the University of California as Yolo loam.[1] From 1912 to 1915, inclusive, 3.48 acres were utilized, divided into 15 square checks, averaging 0.23 acre each. The schedule of irrigation followed during the first two years included, in addition to check plats receiving no irrigation, total applications of 12, 24, 36, and 48 inches in depth. This same schedule was continued throughout the series of experiments, except that beginning in 1912 additional checks were provided that received depths of 18 inches and 60 inches, respectively, per year. The checks that received depths of 12, 18, and 24 inches were subjected to single applications at the rate of six acre-inches per acre. With total depths of 30, 36, 48, and 60 inches, individual applications were of 7.5 inches, 9 inches, 12 inches, and 15 inches, respectively. In 1910, 1912, and 1913, following winters of low rainfall, the first irrigations of the season were given immediately after the first cutting, but in 1911, 1914, and 1915, after relatively wet winters, irrigation began after the second cutting. Water was applied to the plats at Davis from a pumping plant on the tract which delivers approximately 0.9 cubic foot per second, and throughout the series of experiments the practice was to irrigate just as soon as possible after removing the crop from the field. In most cases the water was distributed in slip-joint pipe because it was not possible otherwise to obtain even distribution with the small irrigation head available. In every case, yields were weighed at the time of removal from the fields.

In the time of cutting, raking, shocking, and hauling the hay, standard field practices always were observed. That is to say, the alfalfa usually was cut when one-tenth to one-third was in bloom and the hay

[1]United States Department of Agriculture, Bureau of Soils, Reconnoissance Soil Survey of the Sacramento Valley, California.

generally was raked the same day, shocked the following day, and hauled as soon as it was dry enough to be stacked without heating, never being left until the leaves were dry enough to fall off when handled. The curing and removal of the hay from the field required from five to seven days. As soon as possible after the crop had been hauled from the field, irrigation water was applied.

The following table summarizes the results of the duty of water studies over the six-year period:

TABLE No. 1.

Summary of Alfalfa Duty of Water Investigations at Davis, 1910-1915.

Number of irrigations	Unit depth each irrigation, inches	Depth of water applied, inches	Yield, tons per acre							Average value of hay per acre at $7 per ton[1]	Average cost of production per acre[2]	Average profit per acre
			1910	1911	1912	1913	1914	1915	Average			
None	------	------	3.85	5.94	5.52	2.75	2.89	2.35	3.88	$27 16	$8 73	$18 43
Two	6	12	4.78	7.52	6.51	4.31	5.83	4.84	5.63	39 41	15 37	24 04
Three	6	18	-------	-------	7.02	5.69	8.02	6.46	6.80	47 60	19 35	28 25
Four	6	24	6.00	8.38	8.32	6.89	9.96	7.96	7.92	55 44	23 22	32 22
Four	7½	30	7.53	9.54	9.43	7.97	11.06	8.32	8.98	62 86	26 45	36 41
Four	9	36	7.58	9.33	9.38	8.22	12.48	8.63	9.27	64 89	27 96	36 93
Four	12	48	8.45	9.52	8.63	8.83	10.62	8.05	9.02	63 14	29 10	34 04
Four	15	60	-------	-------	10.17	7.25	10.70	5.55	8.42	58 94	29 44	29 50

[1]Market value of hay, 1910, 1911 and 1912, $11 per ton; 1913, $9; 1914, $4; 1915, $8.
[2]Labor of production, including cutting, raking, shocking and hauling, figured at $2.25 per ton. Water figured at $1.70 per acre-foot. Labor for irrigation figured at $0.50 per acre per irrigation.

Examination of this summary indicates that while both the average maximum yields and the average maximum profits were greatest in the case of annual applications of 36 acre-inches of irrigation water per acre, it is clear that neither the average increase in yield nor the average increase in profits, with applications at the rate of 36 acre-inches per acre per year over the average yields and profits with applications at the rate of 30 acre-inches per acre per year, was large enough to be material with water costing at the rate figured in the Davis experiments. It is plain, however, that to the extent that water costs less than $1.70 per acre-foot, the increase in net profits with annual depth of 36 inches over the figures for annual depths of 30 inches would be correspondingly greater, and very much greater if water were paid for at the flat annual rate of $1.50 or $2.00 per acre, as was the rule in a number of the Sacramento Valley areas included in the general investigation. The significant fact about the results at Davis is that the increase in yield tends to become negligible above annual depths of 30 to 36 inches, indicating that under conditions at Davis, a maximum allowance of 36 acre-inches per acre per year is ample. This is further brought out graphically in the accompanying chart. (Fig. 1.)

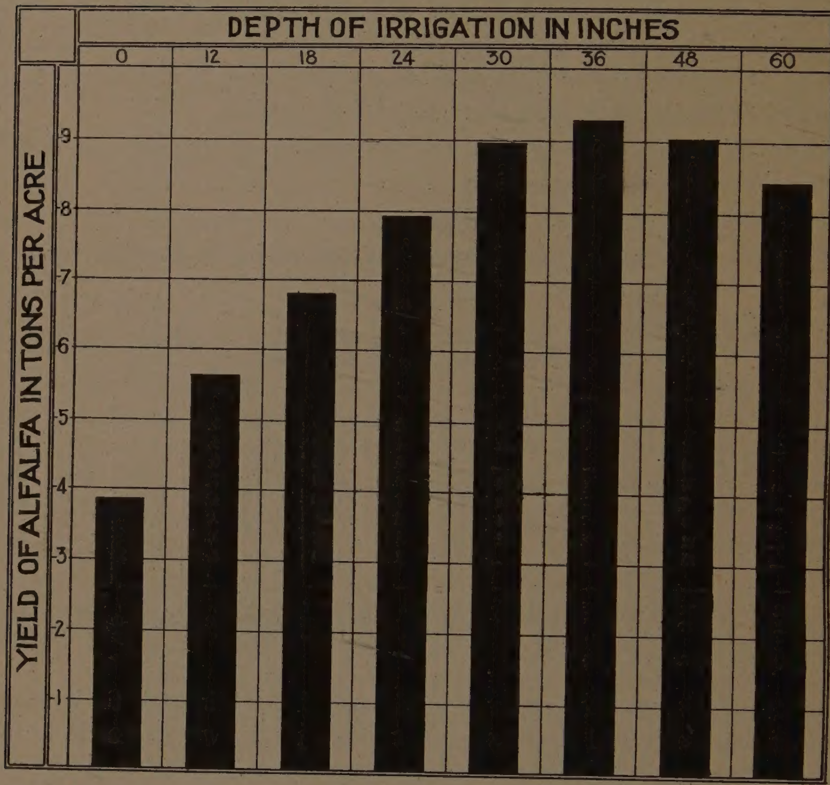

Fig. 1.—Diagram showing results of alfalfa duty of water experiments at University Farm, Davis, 1910 to 1915.

The most marked change from year to year in the relation of the averages to each other took place in the 60-inch applications. The 1912 yield from the most heavily irrigated plat was more than 10 tons per acre, but the average dropped to 8.42 tons per acre by 1915, and had the investigations been conducted longer this average doubtless would have decreased each year. The 1915 yield was only 5.55 tons per acre, owing to the quantity of rank water grass which had supplanted the alfalfa.

A wide variation in the seasonal rainfall and in the length of the growing season was observed at Davis. Both of these factors seemed

to have a decided effect on the yields of hay, as shown by the following table:

TABLE No. 2.

Relation of Climate to Yields of Hay at Davis.

Season	Rainfall	Length of growing season[1]		Average temperature, deg. F.	Number of cuttings	Average yield of hay per acre from all checks
		Dates	Number of days			
1909–1910	11.90	Mar. 22–Oct. 10	202	57.7	6	6.36
1910–1911	23.18	Feb. 27–Oct. 7	222	58.3	6	8.37
1911–1912	9.46	Mar. 3–Oct. 10	221	57.9	6	8.12
1912–1913	8.74	Mar. 4–Sept. 17	197	58.0	5	6.49
1913–1914	28.70	Feb. 6–Oct. 26	262	60.0	6	8.94
1914–1915	20.05	Jan. 23–Oct. 13	263	59.5	6	6.52
Average	17.00	Feb. 23–Oct. 9	228	58.6		7.48

[1]Period between date of last killing frost in the spring and the date of cutting last crop the following fall.

Although no conclusions are drawn from these observations the effect of climatological factors on crop growth and yields under irrigation is shown clearly.

Immediately following the harvesting of the last crop at Davis, on October 13, 1915, five areas, each containing 100 square feet, were laid off on each plat included in the experiment and the number of plants in each area counted. The probable number of plants per acre was figured from the average of these counts. By field count a good stand of mature alfalfa was found to contain an average of one and one-half plants per square foot. With this as a basis of comparison, the following table was compiled:

TABLE No. 3.

Estimated Per Cent of Alfalfa Stand Remaining at Davis at End of Six-year Experimental Period.

Number of plats	Depth of water applied, inches	Number of plants per acre	Per cent of good stand remaining
17, 30		8,625	13.2
18, 29	12	22,216	34.0
19, 28	18	30,928	47.3
20, 27	24	33,977	52.0
21, 26	30	41,382	63.3
22, 25	36	39,422	60.3
23, 24	48	38,333	58.7
31	60	17,598	26.9

This shows the effects of the two extremes in the application of water, especially when it is remembered that the observations on the 60-inch application extended over a period of only four years and in this time the stand, as a result of over-irrigation, was reduced to an estimated average of only 27 per cent of the original.

Soil Moisture Determinations at Davis.

Beginning with 1913 and extending through three years, very complete studies were made of the moisture content of the alfalfa plats. In the table below are given averages of the results of the three seasons observations, representing the number of inches applied and percentages retained by the upper six feet and upper twelve feet of soil. The plats which received no irrigation are not included in this table.

TABLE No. 4.

Acre-inches and Per Cent of Applications Retained by Soil, Davis Alfalfa Plats, 1913-1915.

Number of plats	Number of irrigations per season	Depth of water applied at each irrigation, inches	Amount of water retained in upper 6 feet of soil: Inches	Amount of water retained in upper 6 feet of soil: Per cent of quantity applied	Amount of water retained in upper 12 feet of soil: Inches	Amount of water retained in upper 12 feet of soil: Per cent of quantity applied
18, 29	2	6.0	3.81	63.5	----------	----------
19, 28	3	6.0	5.52	92.0	----------	----------
20, 27	4	6.0	4.43	73.8	----------	----------
21, 26	4	7.5	5.10	68.0	8.00	106.6
22, 25	4	9.0	5.49	61.0	9.56	106.1
23, 24	4	12.0	6.68	55.6	10.32	86.0
31	4	15.0	9.24	61.6	13.09	87.2
Average, 6-foot tests[1]	----------	6.0	4.59	76.4	----------	----------
Average, 12-foot tests	----------	9.5	5.76	[2]60.6	9.29	[2]97.7

[1]Plat 31 omitted from average.
[2]Group averages obtained by giving plat percentages weights proportional to quantities of water applied.

With the exception of plats 18 and 29 and 31, the percentage of water accounted for in the upper six feet of soil decreases with the increase in amount of water applied from 92 per cent for the plats that received three six-inch irrigations to 55.6 per cent for those that received four 12-inch irrigations. The total amounts of water retained in the same depth of soil per season increased with the increase of irrigation water. Examination of quantities retained by the upper 12 feet in plats 21 and 26 and 22 and 25 shows that more water was found in these plats than was applied. It is probable that this condition resulted from a lateral movement from plats 23 and 24 at a depth of seven to nine feet, or immediately above the relatively impermeable clay subsoil found at the ninth foot. This view is supported by the fact that plats 23 and 24 retained only 86 per cent of the twelve inches applied, while the average amount held by plats 21 and 26, 22 and 25, and 23 and 24, in the upper twelve feet of soil, was a little less than 100 per cent. Plat 31, having a finer textured soil, retained more than any other plat and a higher percentage than plats 23 and 24, which received less water.

In 1915, observations were made of the rate of growth of the alfalfa on the various plats. Owing to the fact that the varied irrigation treatments during the three preceding years had resulted in thinning out the stand on some of the plats, the actual rates of growth in 1915 resulted, in a measure, from the effect of these previous treatments. In order to eliminate the effect of thinness of stand and to make the 1915 rates of growth comparable from the standpoint of moisture alone, the growth rate on plats 21 and 26 is taken at 100 for each crop grown and the relative rates on the other plats computed on this basis. Plats 21 and 26 are taken at 100 because thirty inches of irrigation water per annum, the amount given to these plats, evidently represents the most economical duty for alfalfa under the conditions of these experiments. The actual growth rate of the six crops of alfalfa on the plats in 1915 was 49, 51, 112, 96, 106, and 45 pounds per acre per day, respectively. The relative rates of growth for all the plats are given in the following table:

TABLE No. 5.

Relative Rate of Growth of Each Crop of Alfalfa at Davis Experimental Plat, 1915.

Number of plats	Depth of water applied, inches	Relative rate of growth of each crop					
		First	Second	Third	Fourth	Fifth	Sixth
17, 30	----------	47	53	22	22	17	9
18, 29	12	71	61	69	78	39	18
19, 28	18	84	88	73	76	89	45
20, 27	24	104	110	88	92	98	76
21, 26	30	100	100	100	100	100	100
22, 25	36	102	112	117	101	94	100
23, 24	48	104	98	96	110	96	93
31	60	94	86	48	66	42	49

That the preceding winter's rains thoroughly wetted the soil of the experimental tract throughout its entire depth is concluded from the soil moisture observations. Hence conditions in plats 17 and 30 and 21 and 26 for the period of growth of the first and second crops, other than variation in alfalfa stand, may be considered the same, for no irrigation water was applied to any of the plats before the second cutting. The relative rate of alfalfa growth for the first two crops on plats 17 and 30 averaged 50. Hence it appears that the last four cuttings produced 44, 44, 34, and 18 per cent, respectively, of what should have been produced had an average moisture percentage about six per cent above the point at which plants wilt, been maintained, as in plats 21 and 26. Instead, however, the moisture content during the growth period of the last three crops was about seven per cent below the wilting point in the surface foot, slightly below in the second foot, and approximately coincident with it in the lower foot sections.

This amount of moisture is insufficient to support a normal rate of growth. In plats 18 and 29, likewise, the moisture content in the surface foot fell below the wilting percentage shortly after the fourth cutting, and the fifth and sixth crops grew at the rates of only 56 and 26 per cent, respectively, of normal. In plats 19 and 28 the moisture content of the upper two feet was below the wilting point during the growth of the sixth crop, which was unirrigated, and resulted in a rate of growth of only 55 per cent of normal. Plats 20 and 27 showed a moisture percentage in the surface foot coincident with the wilting percentage before irrigation, but seldom approaching that point in the lower depths.

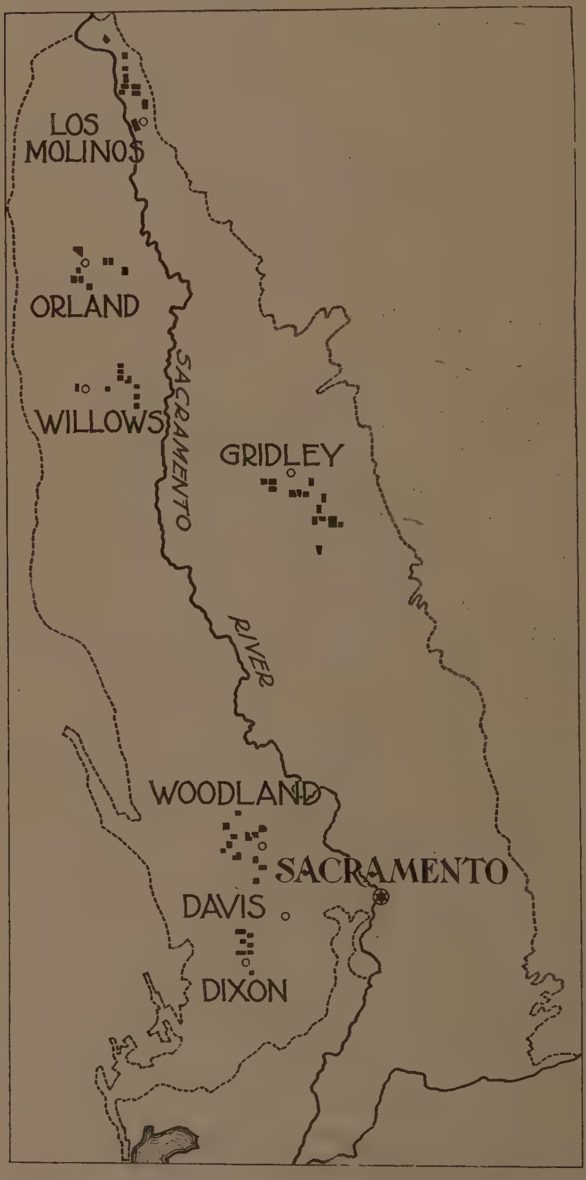

Fig. 2.—Outline map of Sacramento Valley showing location of alfalfa farms on which alfalfa duty of water measurements were made 1913 to 1915.

In plats 21 and 26, 22 and 25, and 23 and 24, very little change took place in the relative growth rates during the season, or in *average* moisture percentages. In plat 31, however, an increase in moisture percentage took place as the season advanced, and the small relative yields after irrigation began, that is of the last four cuttings, are due to an excess of moisture. Considering the average of the first two cuttings, as normal,

the third, fourth, fifth and sixth crops were respectively 53, 73, 47, and 54 per cent of normal, or an average of 56 per cent for the period of the irrigation season. On the same basis, plats 21 and 26, 22 and 25, and 23 and 24 produced respectively 100, 97, and 98 per cent of normal yields.

INVESTIGATIONS ON SACRAMENTO VALLEY ALFALFA FARMS.

In selecting the areas away from Davis to be included in the wider investigation (Fig. 2), care was taken to include enough fields so that there would be represented the major soil types of the valley as determined by the soil surveys of the bureau of soils and of the college of agriculture of the University of California, whose soil classifications have been followed in this report; also, to give the investigations as wide a geographical distribution as possible, so that the differences in rainfall could be taken into consideration. Accordingly, during the irrigation seasons of 1913 and 1914, between 40 and 50 representative farms were under observation in the neighborhood of Gridley, Los Molinos, Orland, Willows, Woodland, and Dixon, this work being supplemented in 1915 by detailed studies on a single ten-acre tract five miles northeast of Willows, and by general observations and measurements on four other farms.

While the experiments at Davis were conducted under normal field conditions, without departure from what may be termed merely good field practice, in the investigations on Sacramento Valley alfalfa farms, it was impossible, except in one case, to vary the quantities of irrigation water applied. Nevertheless, it was believed that by taking careful account of the irrigation water in the soil immediately before and shortly after irrigation, and by careful measurement of the amounts of water applied and of the crops taken off, it would be possible to obtain a satisfactory basis for correlation of results. Thus the investigation became not merely a measurement and study of the amounts of water used, but more particularly a study of the underground distribution of the irrigation water applied, and a critical inquiry into the capacity of the various soils of Sacramento Valley to retain irrigation water, the amounts or percentages of moisture necessary to maintain alfalfa growth, and the best means of maintaining these amounts under the conditions met.

Procedure.

Wherever possible, standard weirs were installed for measuring the water applied to the fields. Where sufficient fall was not available for this, and also where registers were not used, those conducting the field investigations made a sufficient number of current meter gagings or gage readings to give satisfactory evidence of the amounts of water being used. In a few instances, chiefly at Orland, automatic water registers were installed for obtaining continuous records. While all

the fields under observation were watched carefully for waste at the lower ends of the checks, no measurable waste was found. There was no waste of consequence off the fields where the largest quantities were used, such waste as did occur coming on the fields having heavy soils that failed to absorb the water.

In addition to measuring the quantities of water applied to the surface of the fields, the underground distribution of the water, following its application, was traced in as many cases as possible through soil sampling and moisture determinations. In taking soil samples, extreme care always was exercised to avoid holes previously bored. It was found impossible to trace the underground distribution of the irrigation water in all of the fields, but some work of this nature was done in each section studied. Borings were made to a depth of at least six feet and at least three points in each field one or two days before each irrigation and again at approximately the same points from two to five days after each irrigation. While this method left an interval of several days between soil sampling during which some moisture was used by the crops, and while it also failed to take account of the evaporation losses immediately following irrigations, substantially the correct relation was found by extending the moisture percentage curves, shown in the diagrams accompanying the text, so as to coincide with the moisture percentages immediately before and after increases due to the irrigations. In taking the soil samples for moisture determinations, small tins with an approximate capacity of one-half pound, and with tight-fitting covers, were filled from the center of each foot section; that is, at one-foot intervals beginning one-half foot below the surface and extending to five and one-half feet. During 1913 these samples usually were dried in electric ovens at local field headquarters, but in 1914 all were forwarded to the laboratory at Davis where they could be handled more conveniently. The tins were shipped in tight-fitting compartments in specially made boxes holding 18, a sufficient number of check determinations having been made in the field and in the laboratory to insure that moisture loss in transit would be negligible.[1]

In measuring the areas of the alfalfa fields under investigation, all principal supply ditches were eliminated, but the areas reported include borders and levees and small field distributing laterals which carried the water from the main supply ditches to the checks.

A number of considerations were held in view in making the soil moisture determinations connected with these investigations. In the first place it was desired to ascertain the depth of percolation of the

[1]Weighing of about 700 samples both in the field and in the Davis laboratory showed an average loss slightly less than 0.1 per cent during an average time of 36 hours.

irrigation water in order to know in a general way whether it was getting into the soil sufficiently to meet the needs of the crop, and also whether any appreciable amount was passing below the zone of greatest root growth, generally taken to lie within the upper six feet of soil. In order to express this underground distribution of the irrigation water in a way that would be generally intelligible, the moisture content of each of the upper six feet of soil was first determined in inches per foot of depth of soil and the amounts of water added by irrigation then were determined; also, in inches per foot in depth of soil, on the basis of the borings before and after irrigations. Thus, with the water content of the upper six feet of soil before irrigation known (in some cases the upper 9 or 12 feet), and with an accurate measurement of the amount of water applied to the fields, it was possible to estimate quite closely the proportion of the water that remained or was utilized immediately and the proportion that passed below the depths studied.

Another consideration in view in these determinations was to ascertain the relative amounts of irrigation water contained in the upper six feet of soil as compared with the quantities necessary to prevent wilting of the plants.[1] It was reasoned that this information would indicate, with considerable accuracy, the quantities of water necessary to apply to the several types of soil to meet adequately the needs of the crop.

A final consideration, in view in these studies of the underground distribution of the irrigation water, was the frequency with which irrigation water should be applied in order to meet fully the needs of the plants. In other words, it was desired to learn to the extent possible in the investigation the relative advantages of single irrigations between cuttings and of the more frequent irrigations given to alfalfa in some sections and on some soils. It is plain, for instance, that the less retentive a soil, the greater the frequency of applying irrigation water; also, that the "tighter" the soil, the greater the difficulty of getting into it at one time the amounts of water needed to mature a cutting. This last consideration was especially prominent in connection with the gravelly soils near Orland and the very heavy soils found in some of the sections about Willows. In fact, it was the difficulty of getting irrigation water into heavy soils that led to the continuation

[1]Expressed technically, the quantities of irrigation water in the soil over and above the "wilting coefficient." For a discussion of this term and its application see United States Department of Agriculture, Bureau of Plant Industry Bulletin 230. In this report the simpler terms, "wilting point" or "wilting percentage" are used.

of the investigations during 1915 on a single typical field northeast of Willows.[1]

In the course of the three years of investigation approximately 11,000 moisture determinations have been made, not including those made for the plats at Davis. Of these, 8,000 determinations were for moisture-holding capacity. The soil samples used in these determinations were taken with two-inch soil augers of the posthole type. The field and laboratory records were made on special forms devised for the investigation, and in the soil moisture determinations at Davis a special electric oven was used, the soil being heated to a temperature of 105° to 115° centigrade.

In every case where the amount of water used was measured, the crop yields were ascertained by the most satisfactory means available. In some cases crops either were sold in bulk according to scale weights, or baled, making exact weights available. In a few cases stacks were measured or a sufficient number of shocks to be representative of the whole were hauled to nearby scales and the average weight per shock obtained. In a large number of cases the average weight of shocks was ascertained by weighing on the ground by means of special apparatus devised for the purpose. (Plate I, Fig. 1.)

Gridley Area.

Investigations were conducted here in 1913, only, the work being discontinued after that year because of the high water-table and the consequent impracticability of tracing the underground distribution of the irrigation water applied. Work was done on 14 tracts varying from three acres to 67 acres in size. (Fig. 3.) All of the fields studied received water from the Sutter-Butte canal, which takes its supply from Feather River. The charge for water for alfalfa is $2 per acre per year except to some early settlers who pay $1.

The building of the Sutter-Butte canal system and the introduction of irrigation into this area in 1905 was not accomplished without difficulty. Like other sections of Sacramento Valley, the area was devoted to dry grain farming, although fruit was grown in some sections, also without irrigation. In less than ten years the most skeptical of the old-time grain farmers have become convinced that irrigation is profitable and essential in the up-building of the section. But irrigation has

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[1] In ascertaining the capacities of the various soils under observation in the investigation to retain irrigation water and the rates of percolation of the irrigation water applied, it was necessary to make numerous technical studies which it is not desirable to report in this bulletin. The ascertainment of the water-holding capacities of the various soils and of the amounts of moisture necessary to be present to prevent wilting have, for instance, involved the making of apparent and real specific gravity determinations, physical analyses of the soil in the various fields, and the development and checking of special methods of volume-weight determinations of soils "in place." In some of these studies the cooperation was received of Professor Charles F. Shaw, and assistants, of the Division of Soil Technology of the Department of Agriculture of the University of California.

PLATE I.

Fig. 1.—Weighing alfalfa hay in the field.

Fig. 2.—Measuring the irrigation "head" with a current meter on Hofhenke alfalfa farm, Los Molinos.

brought problems relating to drainage and the conservative use of water, which are yet to be solved. The average annual rainfall at Biggs, four miles north of Gridley, is 22.24[1] inches.

The soils of the Gridley area have been classified by the bureau of soils and the University of California as Madera and Gridley loams, undifferentiated. Naturally, in a broad classification many departures are to be found. Southeast of Gridley there occurs a body of silt loam within which were located a number of the tracts included in the investigations in 1913. Under most of the soils a noncontinuous hardpan is found within six feet of the surface and occurs frequently within 18 inches, or again may be absent entirely. To quote from the report of the reconnoissance soil survey by the bureau of soils and the University of California.[2]

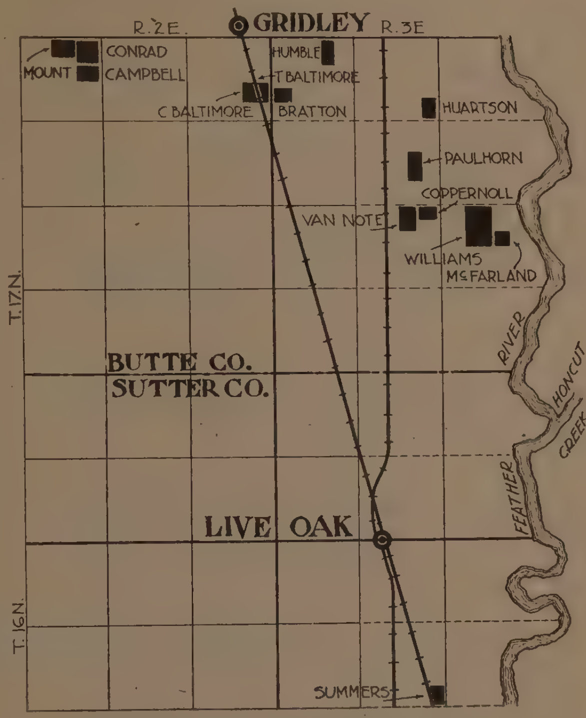

Fig. 3. Map of Gridley area showing location of alfalfa farms under investigation, 1913.

It will be noted in the description of the individual tracts mentioned later that ground water was found in many fields within three feet to five feet of the surface. As far back as 1907 it stood within six feet of the surface under large areas and after a few days of irrigation rose, in many cases, to within three feet of the surface. In general, the water-table seems to fluctuate over wide ranges and to vary considerably within each season. The need for drainage is well recognized and in some sections it has been or is being provided.

[1]Weather Bureau, Annual Summary for 1915.

[2]U. S. Dept. Agr., Bureau of Soils, Reconnoissance Soil Survey of the Sacramento Valley, California, p. 87. The hardpan layer in these soils is variable, being in places a thin stratum of easily fractured gray material, usually high in calcium carbonate. In other places it is a very thick, cemented mass lying near the surface. In still other places it is a semicemented mass of mottled grayish and reddish-brown color. The hardpan has a direct and important influence upon the crop value of the soils of this group. As a whole they are friable, easily tilled and retentive of moisture.

Most of the land planted to alfalfa in the Gridley section is prepared in border checks 30 feet to 60 feet wide and 300 feet to 1,000 feet long. Many of the early settlers used rectangular checks with from five to seven to the acre. In applying water to the border checks, which now predominate, an irrigating head of 10 to 15 cubic feet per second is commonly used, most generally divided between two or three checks. The cost of preparing land for irrigation of alfalfa has averaged from about $15 to $20 per acre. The first irrigation of alfalfa generally is given after the first crop of hay is removed, usually in May or early June. Subsequent waterings follow each cutting with the exception of the fifth or last.

As indicated in Table No. 6, the average use of water on the 14 farms under observation in 1913 was 3.31 acre-feet per acre for the season, and the average total yield from five cuttings of alfalfa was 6.19 tons per acre, this yield having been reduced as a result of an invasion of grasshoppers. The greatest quantity used was 4.98 acre-feet per acre applied in five irrigations, and the least was 2.04 acre-feet per acre applied in four irrigations. In several cases the extravagant use noted was due to the inexperience of the irrigator or to a lack of attention when water was being applied. The fact that water usually was sold to irrigators at a flat rate of $2 per acre and with little restraint exercised by the canal company, had a tendency to promote extravagant use. A change in the method of selling water from a flat rate per acre to the quantity basis is desirable, and would to some extent obviate the dangers of overirrigation.

The underground distribution of the irrigation water applied was traced on the Huartson and Williams fields in the Gridley area in 1913.

Huartson Field. The soil is a loam of the Madera and Gridley series, generally uniform to a depth of six feet, and highly permeable. A noncontinuous hardpan about six inches thick is encountered from four to six feet below the surface. Below this is a rather porous, coarse, sandy loam to a depth of about ten feet, with a very impervious, compact, blue clay underlying to a depth of 20 to 50 feet. This field was irrigated four times, moisture determinations being made before and after each of the last three irrigations. At the second irrigation a depth of 7.44 inches was applied, of which 1.68 acre-inches per acre, or 23 per cent, was retained in the upper six feet. A depth of 7.32 inches was given at the third irrigation, of which 5.97 acre-inches per acre, or 82 per cent, was retained in the upper six feet. A depth of 6.84 inches was given at the fourth irrigation, of which 4.88 acre-inches per acre, or 71 per cent, was retained in the upper six feet. In each case four

borings were made before and after irrigations, and ground water generally was found at a depth of approximately six feet, the latter obviously affecting the moisture content of the soil almost to the surface. Borings to a depth of six feet after the fourth irrigation indicated that almost all of the pore space in the sixth foot of soil was filled with water. Considering the last three irrigations together, it was found that 58.1 per cent of the quantity of water applied was retained in the upper six feet, this being increased to 73 per cent by adding an estimated quantity for loss between irrigations and soil borings. Throughout the period of the last three irrigations, the moisture content below the second foot in depth was far above the wilting point. Considering the high ground water level under this field it is obvious that even the 6.84 to 7.44 acre-inches per acre applied at single irrigations to this field were slightly excessive.

Williams Field. The soil is a little more compact and less permeable than that in the Huartson field. Five irrigations were given in 1913 and moisture determinations were made from four borings before and after the second, third, and fourth, the depths of water applied in these three irrigations being 6, 4.44, and 7.20 inches, respectively. In boring for soil samples it was attempted to go to a depth of six feet, but the high water-table prevented satisfactory results below a depth of three feet. The average quantity of water applied at the second, third and fourth irrigations was 5.88 acre-inches per acre, of which an average of 47 per cent was retained in the upper three feet of soil.

Results of these investigations are summarized in Table No. 6.

TABLE No. 6.

Summary of Results of Alfalfa Duty of Water Investigations, Gridley Area, 1913.

Name	Soil type	Area, acres	Number of irrigations	Total depth water applied, feet	Number of cuttings	Total yield, tons per acre
J. W. Humble	Silt loam	18.43	4	2.55	5	5.84
T. Baltimore	Silt loam	14.93	4	3.42	5	7.20
F. L. Bratton	Silt loam	3.29	4	3.82	5	6.83
Chas. Baltimore	Silt loam	26.40	5	4.98	5	6.95
W. R. Huartson	Silt loam	7.42	4	2.64	5	9.38
C. W. Van Note	Clay loam	27.20	5	2.37	5	5.97
W. G. Coppernoll	Silt loam	13.96	5	2.83	5	7.28
M. B. Williams	Silt loam, clay loam	67.29	4	2.04	5	5.80
A. J. McFarland	Silt loam	9.44	5	4.16	5	4.19
John Paulhorn	Silt loam	17.10	4	3.93	5	5.88
C. W. Summers	Sandy loam	7.00	4	2.23	5	5.92
G. W. Conrad	Silt loam, sandy loam	37.59	6	3.81	5	4.84
G. L. Campbell	Silt loam, sandy loam	16.76	5	3.89	5	6.13
C. W. Mount	Clay loam	17.41	6	3.70	5	4.54
Averages				3.31		6.19

NOTE.—Rainfall November 1, 1912, to October 31, 1913, 1.16 feet.

DESCRIPTION OF FIELDS IN THE GRIDLEY AREA AND COMMENTS ON IRRIGATION CONDITIONS AND PRACTICES.

J. W. Humble Field. Seeded in 1909. Stand of alfalfa uniform. Water table at 3.5 feet below surface during irrigation season. Field in border checks about 60 feet by 260 to 440 feet, with average grade of four inches in 100 feet. Levees four feet wide on top, 8 feet wide on bottom, and six inches high. Water applied once after each cutting, with the exception of the last. An irrigation head of 4.5 to 6.5 cubic feet per second, divided between two checks, irrigation progressing at rate of .8 to 1 acre per hour.

Thurston Baltimore Field. Seeded in 1911. Field prepared in border checks 35 feet wide and 870 feet long with average grade of eight inches per 100 feet in the upper one-half of the field and four inches per 100 feet from center to lower end. Water applied once after each cutting, with exception of last. Head of eight to ten cubic feet per second being divided between two or more checks, no water being wasted at lower end of checks. Borings were made in 1913 to depth of six feet before and after each irrigation. In the higher part of field water table stood five to six feet below surface, while in lower end it was two feet below, these depths being about constant throughout irrigation season.

F. L. Bratton Field. Seeded in 1908. Stand of alfalfa good. Land in rectangular checks averaging 45 feet by 72 feet. Average irrigation head varied from four to eight cubic feet per second, being divided into four or more checks. Four irrigations given. Use could have been greatly reduced by better location of field ditches and arrangement of checks. The fact that several different men were hired to irrigate also accounts for excessive use of water.

Chas. Baltimore Field. Seeded in 1907. Lies west of Thurston Baltimore tract and has good stand. Water table stood at about 3.5 feet below surface during irrigation season. One-half of field prepared in border checks 30 feet by 400 feet with average grade of five inches in 100 feet, remainder being in rectangular checks 70 by 80 feet. Average irrigation head 4.5 to 6 cubic feet per second, generally turned into two or more checks. Water applied after first and second and before third, fourth, and fifth cuttings. Better results might have been secured in part of field by increasing size of head used on individual checks.

W. R. Huartson Field. Seeded in 1909, has excellent stand. Field in border checks 65 feet by 600 feet with average grade of 2.5 inches in 100 feet. Head of 1.7 to 3.5 cubic feet per second applied once after each cutting except the fifth. Water table five to six feet below surface during irrigation season. Water carefully used and excellent returns secured.

C. W. Van Note Field. Seeded in 1909. Stand good and land well prepared for irrigation. Water table four to six feet below surface during irrigation season. Field in border checks, most of which are 50 feet by 620 feet with average grade of two to three inches in 100 feet. Irrigation head of 8 to 13 cubic feet per second divided among two or three checks, irrigation with latter head progressing at rate of about two acres per hour. Water applied once after each cutting and use conservative.

W. G. Coppernoll Field. Seeded in 1910. Stand good and land well prepared in border checks 50 to 55 feet by 460 to 560 feet, with average grade of five to six inches in 100 feet. Average head of 13 to 16 cubic feet per second divided among three or four checks, the land being irrigated at rate of about three acres per hour.

Milo B. Williams Field. Seeded in 1908. Stand good and preparation of land fair. Water table 3 to 3.5 feet below surface during irrigation season. Field in rectangular and border checks of various sizes, some 80 feet by 200 feet and others 60 feet by 450 feet. Average irrigation head varied from 10 to 16 cubic feet per second, divided into two or three streams. Two men usually irrigated at rate of two or three acres per hour and use was conservative.

A. J. McFarland Field. Seeded in 1909. Stand and preparation of land fair. Field divided into border checks 60 feet by 623 feet with average grade of eight

inches in 100 feet. Average heads of eight to ten cubic feet per second divided between two checks. Inexperience of irrigator and lack of attention during times of watering accounts largely for the extravagant use of water.

John Paulhorn Field. Seeded in 1908. Water table 3.5 feet below surface during irrigation season. Field irrigated by flooding from field ditches, 13 to 15 cubic feet per second being divided into two or three ditches. A more economical use of water could have been attained with better preparation of the land.

C. W. Summers Field. Seeded in 1907. Water table three to five feet below the surface during irrigation season. Field in border checks 55 feet by 465 feet, with average grade of four inches in 100 feet. Average irrigation head of four to six cubic feet per second applied once after each cutting of alfalfa, with exception of fifth, irrigation progressing at rate of one acre per hour.

G. W. Conrad Field. Seeded in 1909. Land well prepared and stand fair. Water table about 3.5 feet below surface during irrigation season. Field in border checks 40 feet by 600 feet, with average grade of 0.6 inch in 100 feet. Levees have bottom width of four to six feet and are six inches high. This tract received six irrigations with average of five to seven cubic feet per second.

G. L. Campbell Field. Seeded in 1911. This tract adjoins Conrad tract and has good stand. Water table 3.5 feet below surface during irrigation season. Field in border checks, some 35 feet by 280 feet, with average grade of four to six inches per 100 feet. Average of five to seven cubic feet per second turned into three or four checks. Sometimes irrigation practised at night and water allowed to waste.

C. W. Mount Field. Seeded in 1910. Land fairly well prepared for irrigation but stand has been damaged by excess of water. Water table about 3.5 feet below surface during irrigation season. Field in border checks 60 feet wide and varying in length from 420 to 1,160 feet, with average grade of two inches per 100 feet. Average of four to six cubic feet per second used and considerable water wasted through carelessness of hired irrigators.

Los Molinos Area.

Investigations were conducted on nine fields near Los Molinos in 1913 and on ten fields in 1914, all lying within the 12,000-acre Los Molinos irrigation project, in Tehama County. (Fig. 4.) The first development under the Los Molinos project was in 1908, and by 1914 about 8,500 acres were under irrigation and about 350 families were living on the project.

The average annual rainfall at Red Bluff, about 15 miles north of Los Molinos, is 26.11 inches.[1] Water for irrigation is obtained from Mill and Antelope creeks and is sold by the water company at the flat rate of $2 per acre with a contract allowance of one-fifth "miner's inch" per acre, a miner's inch being defined as 14,000 gallons in 24 hours.

The irrigation season for the project is fixed at April 1 to October 1, but due to an abundance of water and to the fact that the project is not yet completely under irrigation, the established rules governing the distribution of water have not been enforced. Water is delivered in rotation in heads of two to five cubic feet per second and the usual practice is to irrigate alfalfa once after each cutting with the exception of the fifth or last crop. The most common method of preparing land

[1]Weather Bureau, Annual Summary for 1915.

is in border checks 40 feet to 60 feet wide and 300 feet to 600 feet long, with a usual grade of three inches to six inches in 100 feet. A number of fields, however, have not been prepared for irrigation other than by some "floating" of the surface.

Fig. 4.—Map of Los Molinos area showing location of alfalfa farms under investigation, 1913 and 1914.

During the season of 1913 duty of water measurements under the Los Molinos project were made mostly with a current meter (Plate I, Fig. 2), but in 1914 most of the fields were equipped with rectangular or Cipolletti weirs installed at the entrance of the laterals to the farms. Soil moisture determinations in 1913 were confined to miscellaneous borings and determinations through a part of the season, but in 1914 these determinations were made with fair completeness on five fields. The soils in the Los Molinos area are designated by the bureau of soils[1] as belonging to the Vina series and include mostly clay loams and silt loams.

It is to be noted from the summaries in Tables Nos. 7 and 8 that the actual applications of water varied from 1.42 to 8.46 acre-feet per acre per year, averaging 5.57 acre-feet per acre in 1913 and 4.74 acre-feet per acre in 1914; also that a smaller average use in 1914 gave a larger average yield of alfalfa than was obtained in 1913, undoubtedly due largely to the fact that the rainfall in 1914 was over twice that of 1913. But even when rainfall is added to the irrigation water applied each year there are many instances shown in the summaries where larger quantities of water, both irrigation and rainfall, fail to give proportionate increases of yield. For instance, a total of 6.07 acre-feet of water per acre on the Bundy No. 1 farm gave a yield of 3.02 tons per acre in 1913, whereas a total of 5.08 acre-feet of water per acre on the same farm in 1914 gave a yield more than 90 per cent greater. Again, a total of 4.94 acre-feet of water per acre on the Hofhenke farm in 1913 produced a yield of 8.10 tons of alfalfa, whereas

[1]U. S. Dept. Agr., Bureau of Soils, Reconnoissance Soil Survey of Sacramento Valley, California.

a total of 9.74 acre-feet of water per acre, including rainfall, in 1914 gave a yield of only 5.75 tons, or 28 per cent less.

Soil moisture determinations were made on the Wigno, Bundy, Hofhenke, Geer, and Woodward fields in this area in 1914. The soils of all of these fields were highly permeable. Large quantities of water were applied in each case and the moisture determinations showed beyond a doubt that much water passed below a depth of six feet. In the fine sandy loam soils studied on the Wigno tract the increase in moisture content was as great in the sixth foot as in the surface foot. In the case of the other four fields the increase in the lower depths also was sufficient to indicate that much of the irrigation water passed below the depths reached by the soil augers. Speaking generally of the four fields, the moisture work indicated that as much water would have been held by the soils if less had been applied; also that sufficient moisture was in the soils of all four fields almost throughout the season to keep the percentage above the wilting point. A more complete statement of moisture work on these five fields follows.

Wigno Field. Figure 5 shows diagrammatically the changes of moisture content in this field throughout the irrigation season of 1914 for each foot in depth in the upper six feet of soil.[1] The soil of this field is fine sandy loam of the Vina series, and is very uniform to a depth of 12 feet. The field was irrigated four times in 1914. The first moisture samples were taken May 8th, eleven days before the first irrigation, the average moisture content shown by three borings to a depth of six feet having been 15.65 per cent. An irrigation on May 19 of 5.95 acre-inches per acre raised the moisture content in the upper six feet of soil to 25.71 per cent of the water applied; 90 per cent was retained in the upper six feet, the quantities retained in each foot increasing with the depth. The second irrigation, amounting to a depth of 23.18 inches, was given June 20th, eight borings for moisture samples being made June 18th and June 24th. Only 5.67 of the 23.18 acre-inches applied per acre, or a little less than 25 per cent of the total, was retained in the upper six feet of soil. The third irrigation, amounting to a depth of 15.78 inches, was given July 28, moisture samples being taken from eight holes July 22d and July 30th. A total of 4.90 acre-inches per acre, or approximately 31 per cent of the amount applied, was retained in the upper six feet of soil. The last irrigation, amounting to a depth of 28.04 inches, was given on September 10th, eight borings for moisture samples nine feet deep being made September 7th and again September 14th. A total of 4.83 acre-inches per acre, or 17 per cent of the amount applied, was retained in the upper nine feet, 12 per cent, or 3.48 acre-inches per acre, being retained in

[1]More correctly speaking, this and subsequent similar charts show the range of moisture change between irrigations and at each irrigation.

the upper six feet. On November 5th, after the last crop of alfalfa had been removed, eight borings to a depth of six feet showed an average moisture content of 16.53 per cent. Considering the four irrigations together, they are found to average a depth of 18.25 inches each, of which 4.89 acre-inches per acre, or an average of 26.8 per cent of the total was retained in the upper six feet. The diagram shows that the moisture percentage reached or closely approached the wilting point in the upper three feet of soil before each irrigation, but that it

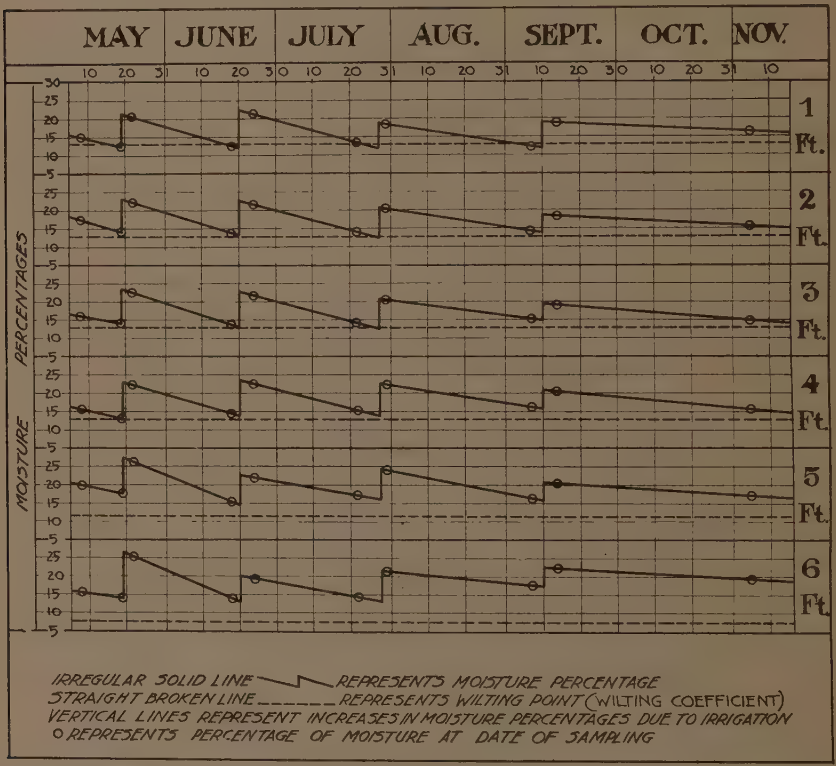

Fig. 5.—Diagram showing seasonal variation in soil moisture percentage, Wigno alfalfa field, Los Molinos, 1914.

was well above the wilting point throughout the season in the third, fourth, and fifth feet below the surface.

Bundy Field. Variations in moisture percentages in this field are shown in figure 6. The soil of this field is a loam of the Vina series, uniform to a depth of at least 12 feet. Four irrigations were given in 1914, 17.72, 12.20, 11.55, and 7.77 acre-inches per acre, respectively, being applied. Six borings were made to a depth of six feet before and after each of the first three irrigations and to a depth of nine feet before and after the fourth irrigation, the moisture determinations

indicating that 4.01 acre-inches per acre, or 23 per cent, was retained in the upper six feet at the first irrigation, 3.27 acre-inches per acre, or 27 per cent, at the second irrigation, 4.03 acre-inches per acre, or 35 per cent, at the third irrigation, and 4.73 acre-inches per acre, or 61 per cent, at the fourth irrigation. The average quantity of water applied in the four irrigations was 12.30 acre-inches per acre, of which an average of 4.03 acre-inches per acre, or 32.5 per cent of the amount applied, was retained in the upper six feet of soil. In this field, as shown by the diagram, the moisture percentage reached the wilting point only in the first foot.

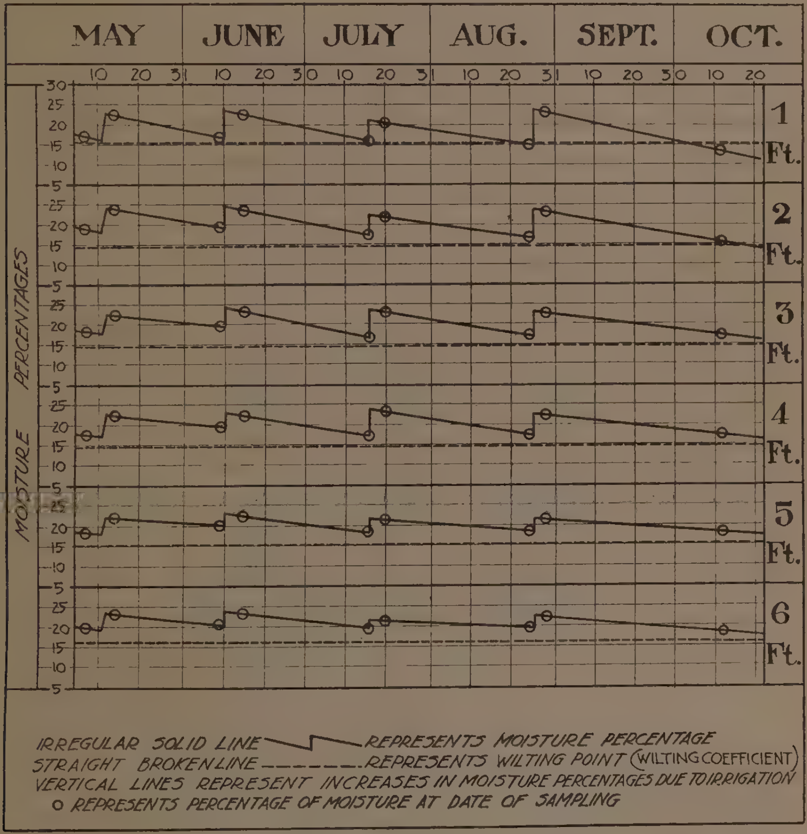

Fig. 6.—Diagram showing seasonal variation in soil moisture percentage, Bundy alfalfa field, Los Molinos, 1914.

Hofhenke Field. Variations in soil moisture percentages in this field are shown in figure 7. Only in August and in the surface foot of soil did the moisture percentage drop to the wilting point. The soil of this field is loam of the Vina series. Irrigations were given in 1914 on June 1st, July 11th, August 16th, and September 21st, the depths

of water applied being, respectively, 18.76, 15.74, 18.86, and 13.22 inches. Moisture determinations were made to a depth of six feet before and after the first three irrigations and to a depth of nine feet before and after the fourth, nine borings being made before and after the first irrigation, and 12 before and after each of the others. The quantities of water retained in the upper six feet of soil in the four irrigations were 5.42 acre-inches per acre, or 29 per cent, at the first irrigation, 3.78 acre-inches per acre, or 24 per cent, at the second irrigation, 5.36 acre-inches per acre, or 28 per cent, at the third irrigation, and 3.50 acre-inches per acre, or 26 per cent, at the fourth irrigation. At the latter irrigation 4.65 acre-inches per acre, or 35 per cent, was retained in the upper nine feet of soil. The average depth at each of the four irrigations was 16.62 inches and the average quantity retained in the upper six feet of soil was 4.51 acre-inches per acre, or 27.1 per cent of the total. Adding the estimated loss between irrigations and soil sampling, the average quantity retained in the upper six feet of soil for each of the four irrigations was 5.59 acre-inches per acre, or 34 per cent of the amount applied.

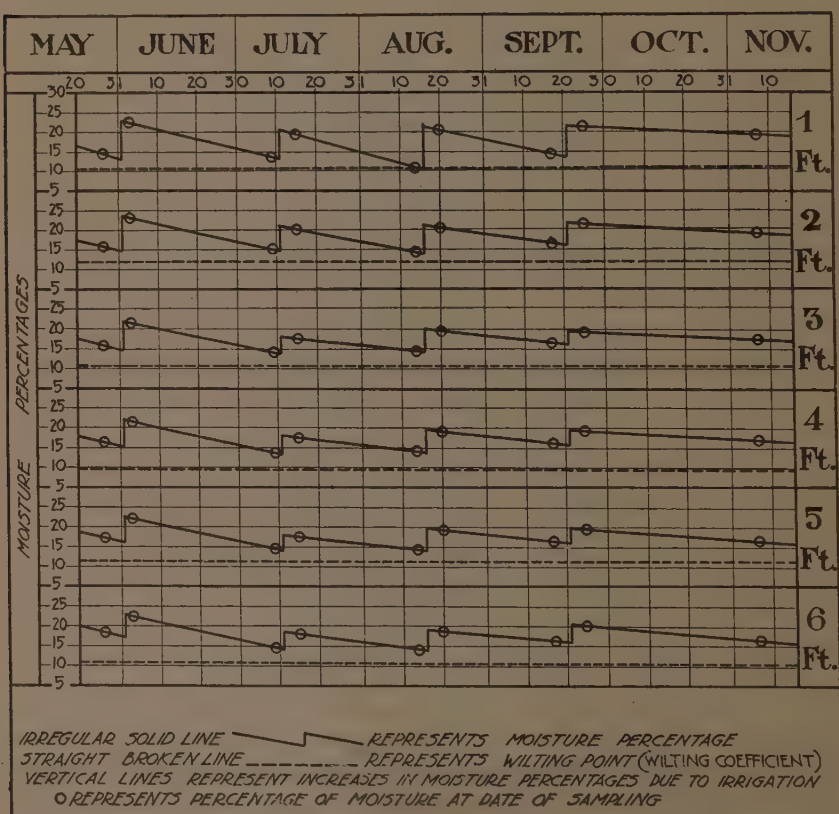

Fig. 7.—Diagram showing seasonal variation in soil moisture percentage, Hofhenke alfalfa field, Los Molinos, 1914.

Geer Field. Variations in soil moisture percentages in this field are shown in figure 8. The soil of this field is classed as a clay loam of the Vina series, the upper two feet being distinctly heavier than the underlying soil, which approaches a silt loam very closely. The diagram shows the wilting point was reached or closely approached in the latter part of July nearly to the full depth of the six feet sampled. Four irrigations were given in 1914, the respective depths applied being 24.00, 18.19, 12.15, and 24.34 inches. Twelve borings for mois-

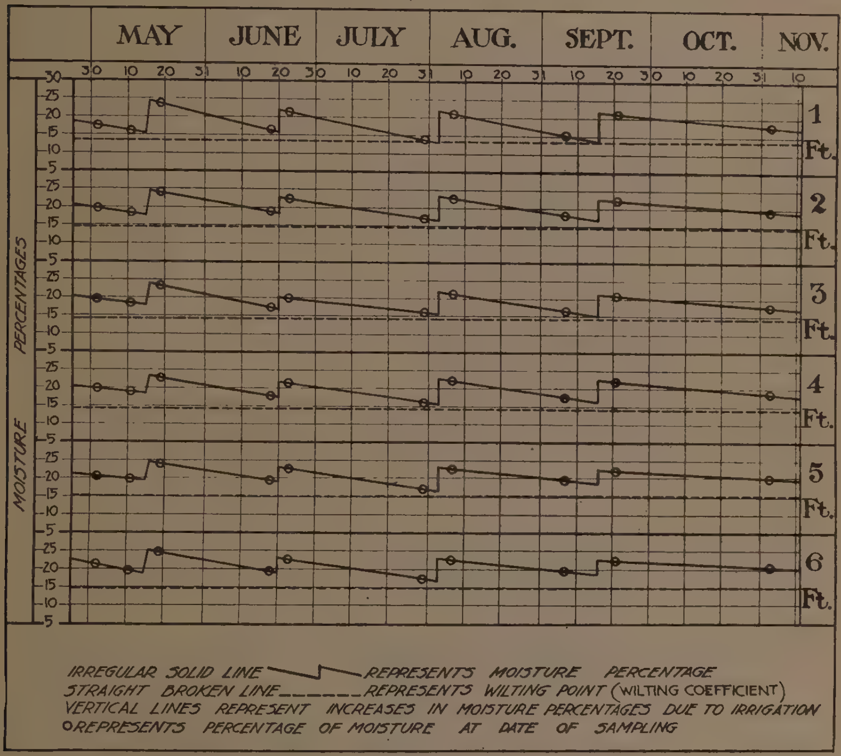

Fig. 8.—Diagram showing seasonal variation in soil moisture percentage, Geer alfalfa field, Los Molinos, 1914.

ture determinations were made to a depth of six feet before and after the first three irrigations and to a depth of nine feet before and after the fourth. These show that the upper six feet of soil retained 5.59 acre-inches per acre, or 23 per cent, at the first irrigation, 3.28 acre-inches per acre, or 18 per cent, at the second irrigation, 5.37 acre-inches per acre, or 44 per cent, at the third irrigation, and 3.76 acre-inches per acre, or 15 per cent, at the fourth irrigation. At the latter irrigation the upper nine feet of soil retained a total of 4.78 acre-inches per acre, or 20 per cent of the whole. The average depth applied at each of

the four irrigations was 19.67 inches, of which 4.50 acre-inches per acre, or 22.9 per cent, was retained in the upper six feet. With correction for the amounts lost between irrigations and the soil sampling, based on the Davis experiments, an average of 5.58 acre-inches per acre, or 28.4 per cent of the total, was retained in the upper six feet of soil.

TABLE No. 7.

Summary of Results of Alfalfa Duty of Water Investigations, Los Molinos Area, 1913.

Name	Soil type	Area, acres	Number of irrigations	Total depth water applied, feet	Number of cuttings	Total yield, tons per acre
E. A. Bundy, No. 1	Silt, clay loam	8.97	4	4.91	5	3.02
E. A. Bundy, No. 2	Silt loam	4.31	4	6.06	5	7.86
R. W. Ballard	Silt loam	10.18	4	6.01	5	5.38
G. B. Engle	Light gravelly clay loam	17.15	5	4.46	5	3.78
G. H. Geer	Clay loam	9.21	4	7.41	5	7.84
J. F. Hofhenke	Silt loam	24.59	4	3.78	5	8.10
S. B. Reece	Clay loam	13.50	4	6.09	5	4.46
John Risse	Silt loam	15.00	4	6.38	5	5.58
A. Wigno	Silt loam	9.13	4	5.08	5	6.29
Averages				5.57		5.81

NOTE.—Rainfall at Red Bluff November 1, 1912, to October 31, 1913, 1.16 feet.

TABLE No. 8.

Summary of Results of Alfalfa Duty of Water Investigations, Los Molinos Area, 1914.

Name	Soil type	Area, acres	Number of irrigations	Total depth water applied, feet	Number of cuttings	Total yield, tons per acre
E. A. Bundy, No. 1	Silt, clay loam	8.97	4	2.84	5	5.78
E. A. Bundy, No. 2	Silt loam	4.31	4	4.10	5	8.40
O. W. Chambers	Gravelly clay loam	3.08	6	1.42	6	4.44
G. B. Engle	Light gravelly clay loam	23.35	6	3.46	5	4.85
G. H. Geer	Clay loam	9.21	4	6.56	5	6.06
J. F. Hofhenke	Silt loam	13.27	4	8.46	5	5.75
	Silt loam	11.32	4	5.55	5	
S. B. Reece	Clay loam	13.50	4	5.47	5	5.68
A. Wigno	Silt loam	6.70	4	6.08	5	6.68
H. N. Woodward	Silt, clay loam	9.08	4	3.95	5	8.31
Averages				4.74		6.22

NOTE.—Rainfall November 1, 1913, to October 31, 1914, 2.74 feet.

DESCRIPTIONS OF FIELDS IN THE LOS MOLINOS AREA AND COMMENTS ON IRRIGATION CONDITIONS AND PRACTICES.

E. A. Bundy Field No. 1. Seeded in 1911. Stand of alfalfa fair. Field divided into seven border checks 80 to 90 feet by 630 feet, with average grade of four inches in 100 feet. Slope across some of checks is uneven, giving unequal distribution of water over surface. Small irrigation heads, ranging from one and one-half to two cubic feet per second, used, requiring more than two days to complete irrigation. Increased yields could have been obtained by better management, particularly by cutting alfalfa at proper time.

E. A. Bundy Field No. 2. Seeded in 1909. Stand of alfalfa good. Field divided into two parts by distributing ditch and every 30 to 40 feet cuts made in ditch bank through which water passes to field. Distribution not uniform over surface,

owing to high spots. Irrigation heads of one to two cubic feet per second applied once after each cutting, except fifth.

R. W. Ballard Field. Seeded in 1907. Stand fair but becoming thin in scattered spots. Field has not been checked and is irrigated by flooding from field ditches, which gives an unequal distribution. Irrigation head usually two and one-half to three and one-half cubic feet per second. Amount of water used on this field could be reduced materially by preparing the land in border checks. Several crops damaged by grasshoppers.

G. B. Engle Field. Seeded in 1911. Stand of alfalfa fair but field rather poorly prepared for irrigation. Irrigation head of one to two cubic feet per second divided into one or two checks varying greatly in size but averaging about 30 by 300 to 600 feet. Grasshoppers reduced yield in 1913.

G. H. Geer Field. Seeded in 1908. Field had excellent stand of alfalfa and considerable care exercised in preparing for irrigation. Border checks of 60 feet by 310 feet with average grade of about three inches in each 100 feet. Usual practice was to turn about five cubic feet per second into one or two checks. Excessive use of water due largely to the irrigator and abundance of water.

S. B. Reece Field. Seeded in 1908. Field had fair stand of alfalfa but not very well prepared. Checks rectangular, ranging from about one-fifth to three-fourths acre in extent. Average irrigation head of five cubic feet per second divided among two or three checks. Field was leased to tenants who did not exercise the best of care in applying water or in handling crop.

J. H. Hofhenke Field. Seeded in 1911. Stand excellent and land well prepared in border checks 40 feet by 400 to 450 feet, with average grade of five inches per 100 feet. Usually five cubic feet per second was divided between two checks.

A. Wigno Field. Seeded in 1911. Stand of alfalfa good, but land not very well prepared for irrigation. Field irrigated by flooding from field ditches, head varying from four to five cubic feet per second.

John Risse Field. Seeded in 1909. One of the oldest fields in the area and stand becoming thin. Field irrigated by flooding from field ditches with average head of five cubic feet per second. Distribution of water not uniform owing to slight irregularities in ground surface.

H. N. Woodward Field. Seeded in 1911. Stand good and land very well prepared for irrigation, except about one-fourth acre in northwest corner of field. Average irrigation head of five cubic feet per second usually divided between two border checks 60 feet by 330 feet.

O. W. Chambers Field. Seeded in 1911. Stand good and field well prepared in border checks 50 feet by 500 to 600 feet, with average grade of about two inches per 100 feet. Usually head of about one cubic foot per second turned into a single check.

Orland Area.

Investigations were conducted on five farms in the Orland area in 1913 and on eight farms in 1914, one of the latter, however, being part of one of the fields studied in 1913. (Fig. 9.) All of these fields lie within the Orland project of the Reclamation Service and the project manager assisted materially in the conduct of the work.

The Orland project comprises about 20,000 acres in Glenn and Tehama counties, of which 7,354 acres were irrigated in 1914. The average rainfall at Orland is 19.23 inches.[1] Irrigation water is obtained by the Orland project from Stony and Little Stony creeks, the direct

[1]Weather Bureau, Annual Summary for 1915.

flow being used when available in the early season, and storage at East Park Reservoir on Little Stony Creek being drawn on later. During the seasons of 1913 and 1914, owing to the fact that the project had not been opened formally by the Secretary of the Interior, irrigation water was supplied at a flat rate of $2 per acre. The land in the project, as thus far irrigated, is largely of gravelly nature, which, with an average slope toward the southeast, of 10 to 15 feet to the mile, supplied adequate drainage. Owing to the gravelly character of the land under irrigation, up to the end of 1914, when more land was taken in, it was found impractical to trace the underground movement of the irrigation water applied, with the exception of the O'Hair farm, on which observations of this nature were made in both 1913 and 1914. All measurements of use in the investigations were made by means of Cipolletti or rectangular weirs, and automatic registers were installed on six of the farms. All of the land in the Orland project is in private ownership. Up to 1914 the average individual cropped area was 22 acres. Alfalfa, the only crop covered in the investigation, is the principal crop grown, although practically all of the fruits raised in California are grown commercially to more or less extent in this project.

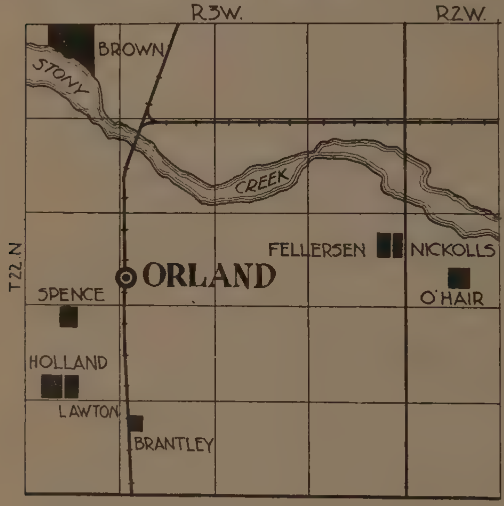

Fig. 9.—Map of Orland area showing location of alfalfa fields under investigation, 1913 and 1914.

The total depth of water applied in 1914, as indicated in tables Nos. 9 and 10, is greater than that applied in 1913, due to a larger supply being available. The yields were larger in 1914 than in 1913, due both to this increased supply and probably also to the very much larger rainfall in 1914. The widest variation in relation between the amount of water applied and the crop yield occurred on the Lawton farm, where 4.29 acre-feet of irrigation water per acre and .82 foot of rainfall produced 5.29 tons of alfalfa in 1913, whereas 9.59 acre-feet of irrigation water and 2.39 feet of rainfall in 1914 increased the yield over 1913 only about 10 per cent. Soil moisture determinations are not necessary in cases of this kind to indicate the needless waste of applying so much water as was applied to the Lawton field in 1914. Fortunately the excessive use in 1914 was but the temporary practice of a renter.

The tracing of the underground distribution of the irrigation water applied in the Orland area was confined to the O'Hair field (Fig. 10), the other fields being eliminated from this work because of the gravelly nature of the soil. The soil of the O'Hair tract lies near the border line between a silt loam and clay loam and is somewhat impregnated with fine gravel at a depth of three to five feet, a coarser gravel being sometimes encountered at a depth of about eight feet.

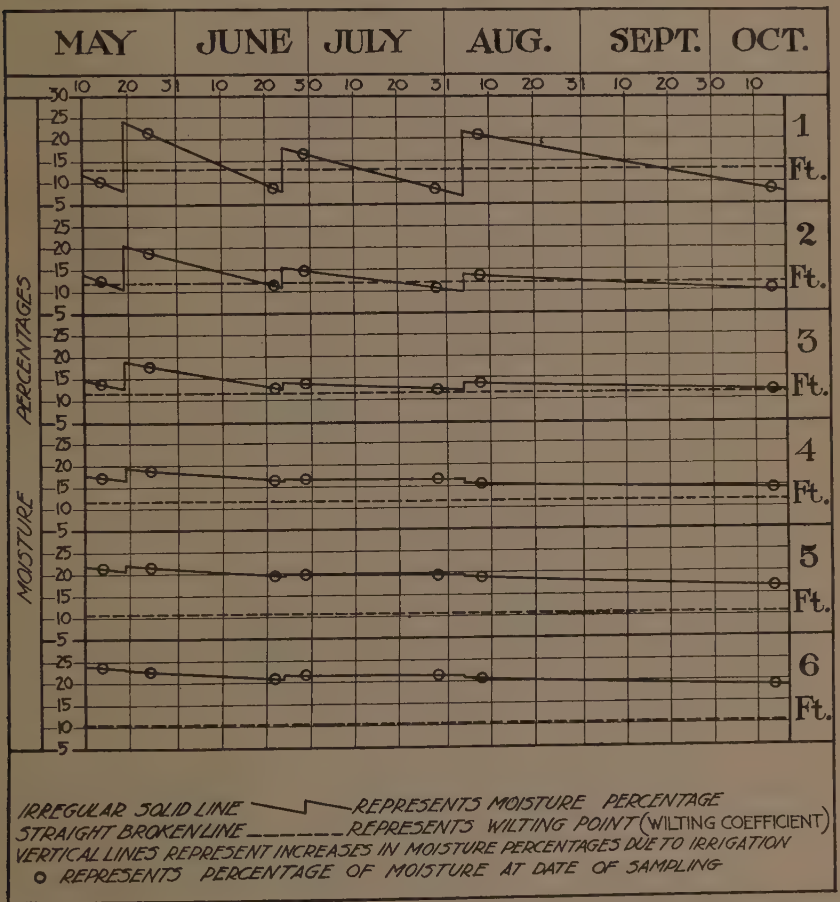

Fig. 10.—Diagram showing seasonal variation in soil moisture percentage, O'Hair alfalfa field, Orland, 1914.

Owing to changing from the sun-dried to the oven-dried method of making moisture determinations, the work of this nature in 1913 was not conclusive. The field received three irrigations in 1914 and nine borings for moisture determinations were made to a depth of six feet before and after each irrigation. In the first irrigation a depth of

6.24 inches was applied, of which the upper six feet retained 3.58 acre-inches per acre, or 57 per cent of the amount applied. Of this about one-half was retained in the surface foot. At the second irrigation a depth of 3.18 inches was applied, of which 2.11 acre-inches per acre, or 66 per cent, was retained in the upper six feet, nearly two-thirds of this remaining in the surface foot. In the third irrigation, a depth of 3.24 inches was given, of which approximately two-thirds remained in the upper six feet, nearly all of this remaining in the surface foot.

The striking condition brought out by the moisture borings in the O'Hair field was that, while the percentage of the irrigation water applied retained in the soil decreased with the depth, the amount of moisture in the soil before irrigations actually increased with the depth, apparently due to the capillary rise of ground water, which stood seven to nine feet below the surface. As a whole, the moisture percentages in the upper three feet of soil did not vary widely from the amount necessary to prevent wilting, and below three feet it was at all times well above the wilting point.

TABLE No. 9.

Summary of Results of Alfalfa Duty of Water Investigations, Orland Area, 1913.

Name	Soil type	Area, acres	Number of irrigations	Total depth water applied, feet	Number of cuttings	Total yield, tons per acre
David Brown	Gravelly clay loam	76.45	7	4.73	[1]3	3.98
C. E. Fellerson	Coarse gravel impregnated with silt and wash loam	32.45	9	2.83	[2]4	4.44
H. M. Lawton	Coarse gravel impregnated with loam	18.61	9	4.29	[2]4	5.29
Roy O'Hair	Silt loam	34.20	5	3.16	[2]4	6.40
A. C. Spence	Coarse gravel impregnated with silt and wash loam	8.06	10	3.91	[2]4	4.35
Averages, not counting field injured by caterpillars				3.55		5.12

[1]Fourth crop destroyed by caterpillars.
[2]Only four crops cut, due to shortage of water.
NOTE.—Rainfall November 1, 1912, to October 31, 1913, 0.82 foot.

TABLE No. 10.

Summary of Results of Alfalfa Duty of Water Investigations, Orland Area, 1914.

Name	Soil type	Area, acres	Number of irrigations	Total depth water applied, feet	Number of cuttings	Total yield tons per acre
David Brown	Gravelly clay loam	76.45	7	5.04	5	5.49
R. F. Brantley	Clay loam	7.75	18	4.03	5	6.13
C. E. Fellerson	Coarse gravel impregnated with silt and wash loam	14.79	8	2.59	5	5.87
H. M. Lawton	Coarse gravel impregnated with loam	18.61	13	9.59	5	5.84
E. F. Nicholls	Coarse gravel impregnated with silt and wash loam	16.66	9	3.25	[1]4	5.26
J. E. Holland	Coarse gravel impregnated with loam	37.00	18	7.56	5	6.26
Roy O'Hair	Silt loam	34.20	3	1.04	[1]4	7.17
A. C. Spence	Coarse gravel impregnated with silt and wash loam	27.70	10	5.56	Pasture	--------
Averages, not counting fields partially or wholly pastured				5.76		5.92

[1]Crop pastured after fourth cutting.
NOTE.—Rainfall November 1, 1913, to October 31, 1914, 2.39 feet.

DESCRIPTIONS OF FIELDS IN ORLAND AREA AND COMMENTS ON IRRIGATION CONDITIONS AND PRACTICES.

David Brown Field. Seeded in 1909. Land in contours, average difference of elevation between checks being seven inches. In many places uneven grading was cause of scattering and poor growth of alfalfa. Variation in character of soil also had a marked effect upon yield, particularly in south half of field, where soil is compact and in spots quite impervious to water. Average head of water delivered varied from four to eight or nine cubic feet per second, divided so that about one to two cubic feet per second was used on each check. Seven irrigations given each year, 1914 showing slight increase in total application over 1913.

R. F. Brantley Field. Seeded in 1912. Stand of alfalfa fair. Field in square checks having average length and width of about 150 feet. The compact clay loam soil is typical of the project, requiring light, but frequent, irrigations. Water applied every eight or ten days throughout irrigation season, with total of 18 applications. Average amount of water applied each time was a little less than three acre-inches per acre. Soil sampling showed that in some parts of the field water penetrated only from 12 to 15 inches, while in other parts there was a fairly uniform moisture distribution to depth of six feet. A short growth of alfalfa always showed spots where moisture was deficient.

Fellerson-Nicholls Fields. Seeded in 1909. In 1913 this tract was subdivided, the east half being purchased by E. F. Nicholls, so that in 1914 records were kept of each piece separately. Stand of alfalfa good. Field originally prepared in border checks 20 to 40 feet by 100 to 1,400 feet, but by constructing a new head ditch through middle of field the maximum length of checks was reduced to 700 feet. Average irrigation head varied from five to seven cubic feet per second, divided into two or three checks. The greater use of water on Nicholls field is attributed largely to lack of experience of the irrigator.

H. M. Lawton Field. Stand of alfalfa good. Field in square checks averaging about one-fifth acre each. The soil of this tract is so well aerated and drained that irrigation can be followed almost immediately by the mower. Field irrigated 13 times in 1914 at intervals of 12 to 14 days, with average irrigation head of 10 to 12 cubic feet per second. Persons who rented this field in 1914 were careless in handling water and used more than necessary.

J. E. Holland Field. Seeded in 1910. This field lies immediately west of Lawton field and has good stand. Field was irrigated about every 14 days with average head of 9 to 11.5 cubic feet per second turned into one or two checks having an average area of one-fifth acre. This proved the most economical way of applying water. Field is so well drained and soil so porous that the water of an irrigation immediately disappears; it was not unusual for owner to cut alfalfa within a half day after water was applied.

Roy O'Hair Field. Seeded in 1910. Stand excellent. Field in border checks about 40 feet by 300 to 1,250 feet, with average grade of 2½ to 3½ inches in 100 feet. Average irrigation head of 7½ cubic feet per second was turned into two or three checks. During 1914 water table was five to six feet below surface, but in the previous year was at depth of eight feet. It was customary to irrigate this field once after each cutting, but in 1914 owner, being afraid of the rising water table, irrigated only three times in the season. Fifth crop of alfalfa was pastured.

A. C. Spence Field. Seeded in 1912. Stand of alfalfa fair. Field in checks about 100 feet square so arranged in relation to field ditches that an irrigation head of five to eight cubic feet per second can be admitted directly into each check. Owing to the extreme porosity of soil, there was little growth of alfalfa on any part of field except that actually receiving water at each irrigation. Two years studies on this tract showed that unless at least five cubic feet per second is turned on a check of coarse gravelly soil, much of water will be lost through percolation before check is covered.

Willows Area.

Investigations were conducted in this area on six farms in 1914, of which five received water from Central Canal. (Fig. 11.) The work was confined to certain heavy types of soil not represented in the investigations elsewhere in the valley and work was hardly under way in 1914 before the fact was revealed that much difficulty was being experienced in getting water to penetrate the soil. The heavy soils encountered are classified in the Soil Survey as Tehama clay and clay loam.[1] These soils are all of compact structure and inclined to be refractory, very sticky when wet, and subject to hard baking in drying. In local areas, drainage is poor and in winters of heavy rainfall considerable damage is done to alfalfa fields by standing water. In some cases in 1914 it was found immediately after irrigation that water which irrigators supposed was penetrating sufficiently deep to meet all water requirements of the plants was in fact penetrating to depths of only 10 to 12 inches below the surface.

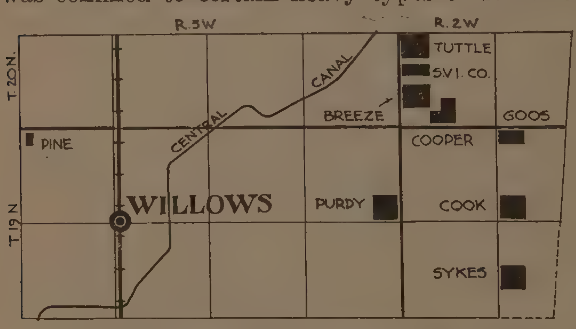

Fig. 11.—Map of Willows area showing location of alfalfa fields under investigation, 1914 and 1915.

[1] U. S. Dept. Agr., Bureau of Soils, Reconnoissance Soil Survey of the Sacramento Valley, California.

The average rainfall at Willows, over a three-year period only, is 16.55 inches.[1] Water carried by Central Canal is obtained by pumping from Sacramento River, except that in the spring and early summer the supply comes from the flood flow of Stony Creek. In 1914 the charge for water was 90 cents per acre and in 1915 it was $1.50 per acre, regardless of time and amounts of application. In general, the border method of preparing land for alfalfa has been followed here, the checks usually being 30 to 60 feet wide and 400 to 800 feet long, with a drain ditch usually provided in the best fields at the lower ends of the checks. Heads of water delivered to the irrigators ranged from three to seven cubic feet per second. In 1914 there was no uniformity in the number of applications given alfalfa, some watering four times and others ten times.

The difficulty encountered in obtaining sufficient moisture penetration in the heavy Willows soils in 1914 suggested the desirability of a continuation of the investigations through the season of 1915 under conditions that would be typical, and where it would be possible to vary the method and time of application. Accordingly, a suitable field was selected five and one-half miles northeast of Willows, and while this work was going on at this field, observations of use alone also were made on four other fields, as reported in Table No. 12.

As compared with the amounts of water used and the result in yields of alfalfa on the other farms under observation in the valley during these investigations, both the use and the yields on the soils under observation about Willows were low—an average use of 1.83 acre-feet of water per acre and an average yield on six farms in 1914 of 4.82 tons per acre. It is to be noted from tables Nos. 11 and 12 that in no case was more than 1.97 acre-feet of water applied, and that in no case, so far as measured, did the yields obtained exceed 5.39 tons per acre. The reasons for these results are not difficult to find when account is taken of the soil moisture determinations made in 1914 on the Purdy, Tuttle, and Pine fields, and in 1915 on the special experimental field northeast of Willows.

Purdy Field. The soil in this field is classed as Tehama clay and is unusually compact. The field was irrigated four times in the season. Three borings for soil moisture determinations were made before and after the first irrigation, eight before and after the second irrigation, and six before and after the third and fourth irrigations. Of the 7.08 inches in depth applied in the first irrigation about 12 per cent entered and was retained in the upper three feet of soil, of which about 11 per cent was in the upper foot. In other words, practically no moisture penetrated below 12 inches. In the second irrigation a depth of 4.56

[1] Weather Bureau, Annual Summary for 1915.

inches was applied, nearly all of which penetrated the soil and of which about 45 per cent remained in the upper foot. In the third irrigation a depth of 4.80 inches was applied, of which approximately one-third remained in the upper foot, with no increase below the second foot. The moisture determinations before and after the fourth and last irrigation, when a depth of 3.84 inches was applied, indicated that the soil became more impervious to water as the season advanced, for about 66 per cent of the amount applied was retained in the first foot, with no significant increase below that.

In comparing the amount of moisture in the surface foot of soil in this field with the amount necessary to maintain plant growth without witling (Fig. 12), it is found that the variation was from three or four per cent below to five or six per cent above that amount through the

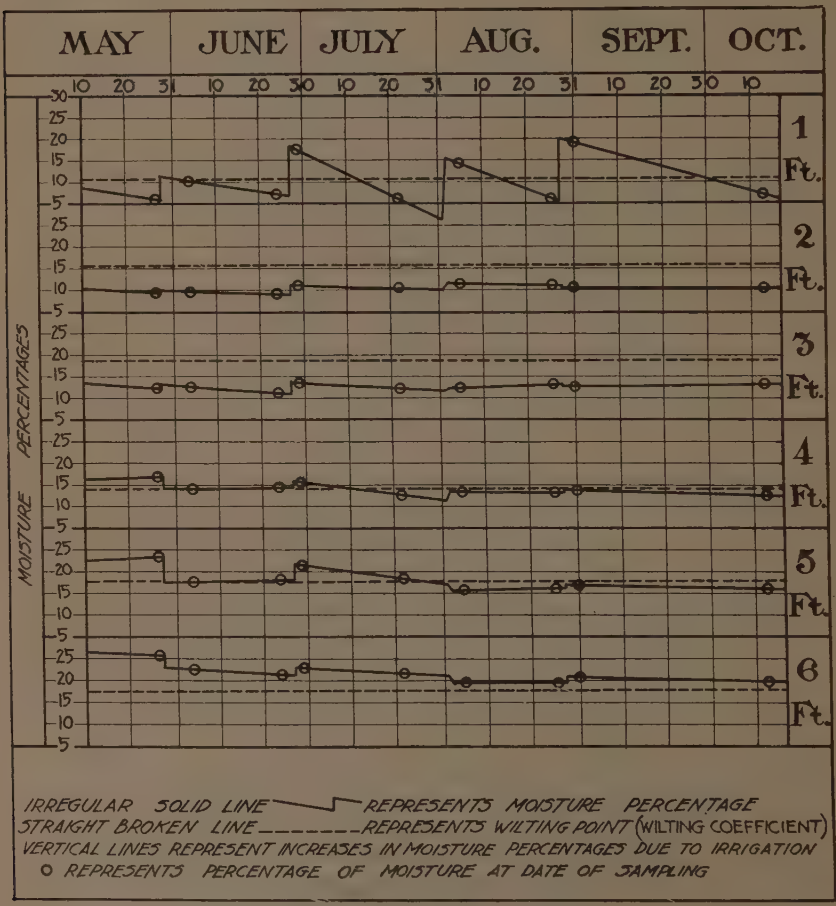

Fig. 12.—Diagram showing seasonal variation in soil moisture percentage, Purdy alfalfa field, Willows, 1914.

season. At no time in the season was the moisture percentage in the second and third foot sections sufficient in itself to prevent wilting, averaging about four per cent below, but at depths of four to six feet there was almost enough to do so.

The most rapid growth of alfalfa in this field occurred during May, when the second crop was being produced. After this the rate of growth decreased continuously, until at the time of the fourth crop. These facts as to growth, taken with the low yield, add to the evidence that the crop suffered through failure of the irrigation water to penetrate the soil below the first foot or two.

Tuttle Field. The soil is similar to that of the Purdy field, but slightly coarser in texture and a little more open and permeable. Moisture determinations were made from ten borings before and after the second irrigation and from nine before and after the third irrigation, a depth of 4.08 inches being applied in the first case, and of 4.16 inches in the second and third. At the second irrigation 93 per cent of the water applied was found to enter the first three feet of soil, about one-half being retained in the first foot. In the third irrigation 44 per cent was retained in the first six feet, three-fourths of which remained in the first foot.

Pine Field. The soil in this field is classed as Willows clay adobe, which was found to be less impervious to water than the Tehama clay of the Purdy and Tuttle fields, and less difficult to handle. Moisture determinations were made from six borings before and after each of the second, fourth and sixth irrigations, the depth of water applied at these irrigations having been 2.40, 3.72, and 4.32 inches, respectively. At the second irrigation all of the water appeared to be held in the first six feet, with approximately one-half retained in the first foot. Of the fourth irrigation about 60 per cent entered the upper six feet, and of this 49 per cent remained in the surface foot. In the case of the sixth irrigation 90 per cent was found to enter the upper six feet, of which nearly one-half again remained in the surface foot.

Experiments in 1915.

In continuing the study on a typical field in 1915 the plan adopted was to give equal total applications of irrigation water to all plats under observation, but to vary the time, depth, and frequency of irrigations. The land used in the experiment was furnished rent free by the local irrigation company, together with irrigation water, while this office met the full expense of the field investigation. The field utilized in this study, with roadways and main canal eliminated, comprised 8.75 acres of alfalfa divided into 21 border checks 60 feet by 300 feet, with an average grade of four inches per 100 feet, and with an average area

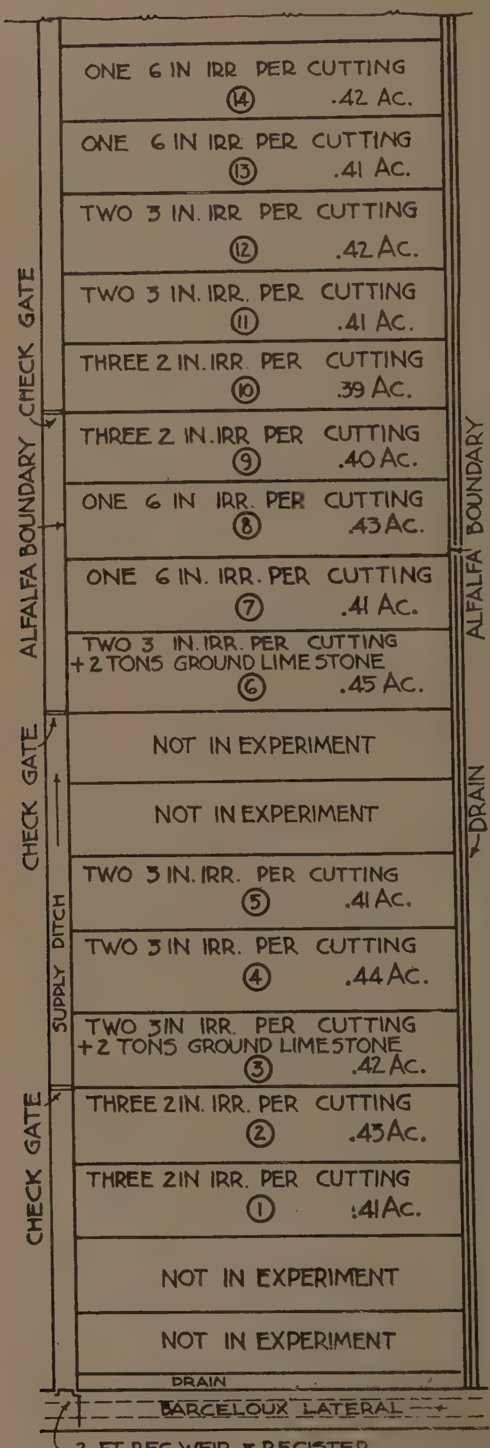

Fig. 13.—Plat of experimental tract, Willows, 1915.

per check of 0.42 acre (Fig. 13.) A drain ditch parallel with the head ditch cared for surface run-off from the lower ends of the checks. The alfalfa was seeded in 1911, following many years of dry grain cropping, and while the stand was not good at the time of these experiments, it was one of the best that could be found on the compact soils of the neighborhood, and, in general, was representative of many alfalfa fields of the locality. At the lower ends of the checks small areas of alfalfa had been killed in previous years by standing water, and these small areas and a considerable number of bare places on the levees and parts of the checks where the stand was comparatively thin were partially responsible for the low yields obtained. Except for the wide distances between the check levees, the field was well prepared for irrigation.

The soil in this field, which is classed as a Tehama clay loam, is grayish in color and of compact structure and refractory nature. When wet it is sticky, and upon drying becomes very hard, but does not check or crack. It is free from both hardpan and gravel and little difference is noticeable between the soil and subsoil. This type of soil was selected because the soil survey maps indicate the presence of about 45,000 acres

of it in Sacramento Valley, very largely east of Willows in the area surrounding this field.

The amount of water used on each of the plats during the season was two acre-feet, an average irrigation head of 2.82 cubic feet per second being generally divided between two checks, although various other sizes of heads were tried. One-third of the twelve checks under observation were irrigated with a depth of six inches, once for each cutting except the last, one-third received two three-inch irrigations between cuttings applied just before and just after the crop was removed, and one-third received three two-inch irrigations, at intervals of about 12 days. (Plate II, Fig. 1.) All of the water entering the field was measured by a 2½-foot rectangular weir and automatic register. (Plate II, Fig. 2.)

For the purpose of increasing, if possible, the perviousness of the soil to water, two checks were treated with ground limestone at the beginning of the season at the rate of four tons per acre. It was not expected that these checks would show much change the first year and they did not. The largest annual yield of alfalfa, 5.07 tons per acre, was obtained from the checks receiving three two-inch irrigations per cutting, an increase of 18 per cent over the lowest yields, 4.42 tons per acre, being secured from the checks that received two three-inch irrigations per cutting, and lowest yield, 4.29 tons per acre, coming from the checks irrigated with one six-inch irrigation per cutting.

While the above increases of yield indicate the desirability of more than one irrigation per cutting, the differences in the one season of investigations were not great. It was evident to those in the field, however, that the more frequent the application of water, the better the moisture condition of the soil. Borings for soil moisture determinations were difficult, except immediately after irrigations, and even then difficulty was encountered below the first foot of soil. Including the 12 plats, a total of 3,408 moisture determinations were made before and after irrigations, and while the chief value of these is in the larger understanding they give of the character of these compact soils, especially with reference to the permeability to irrigation water, they substantiate, to the extent reasonably to be expected, the better results due from the more frequent applications of irrigation water.

In order to gain an idea of the root development of the alfalfa in this field a hole about six feet square and three feet deep was excavated. This also afforded a good view of the cross section of the soil formation. The roots of the plants were carefully removed. It was found that the taproots of the alfalfa were not over one-half inch in diameter and did not extend below a depth of three feet. The main mass of the roots was concentrated in the upper two feet of

soil. The fact that the greater part of the alfalfa plants in this particular field are shallow-rooted is attributed largely to the compact structure of the soil, making moisture penetration difficult.

After removing the soil for root examination some rather surprising results were found in tests made by filling the hole from which they came with water and noting the time required for downward and lateral percolation. Twenty-four hours after the hole had been filled to a depth of three feet there remained in the hole two feet of water. Two weeks later there still remained one foot. Holes two inches in diameter and four feet deep bored 12 inches away from the large test hole showed no lateral percolation. In holes bored six inches from the test hole a slight amount of water had seeped through after 12 hours. Later another hole was excavated in a different part of the field and similar trials made, practically the same results being secured as in the first test. These tests serve to show the impermeability and peculiar physical conditions of the soil represented in this field.

TABLE No. 11.

Summary of Results of Alfalfa Duty of Water Investigations, Willows Area, 1914.

Name	Soil type	Area, acres	Number of irrigations	Total depth water applied, feet	Number of cuttings	Total yield, tons per acre
P. S. Cook	Silty clay loam	15.65	9	1.68	[1]3	1.71
C. F. Goos	Silty clay loam	13.00	10	1.83	5	5.32
L. E. Tuttle	Silty clay loam	35.06	4	1.28	[1]3	3.93
V. E. Breeze	Silty clay loam	35.95	6	1.79	[1]3	1.63
Jas. Purdy	Silty clay	11.37	4	1.69	5	3.75
W. B. Pine	Clay adobe	3.34	7	1.97	4	5.39
Averages, not counting fields pastured				1.83		4.82

[1]Crop pastured after third cutting.

NOTE.—Rainfall November 1, 1913, to October 31, 1914, 2.39 feet.

TABLE No. 12.

Summary of Results of Alfalfa Duty of Water Investigations, Willows Area, 1915.

Name	Soil type	Area, acres	Number of irrigations	Total depth water applied, feet
C. F. Goos	Silty clay loam	13.00	7	1.62
L. E. Tuttle	Silty clay loam	35.06	5	1.75
Geo. Cooper	Silty clay loam	3.01	7	1.53
H. J. Sykes	Silty clay loam	15.60	7	1.94
Average				1.71

NOTE.—Rainfall November 1, 1914, to October 31, 1915, 2.09 feet.

PLATE II.

Fig. 1.—Irrigation of alfalfa on Willows experimental tract, 1915.

Fig. 2.—Weir and water register, Willows experimental tract, 1915.

DESCRIPTIONS OF FIELDS IN THE WILLOWS AREA AND COMMENTS ON IRRIGATION CONDITIONS AND PRACTICES.

P. S. Cook Field. Seeded in 1912. Stand thin in spots but compares rather favorably with other fields in the vicinity. Field irregular in shape and is divided into border checks 40 to 80 feet wide and from 200 to 700 feet in length, with average grade of 3 inches per 100 feet. An irrigation head of 3.5 to 6 cubic feet per second divided between two and four checks. Miscellaneous borings after irrigation showed little moisture below a depth of 12 to 15 inches.

C. F. Goos Field. Seeded in 1911. Stand comparatively good. Land in border checks 40 feet by 600 feet with average grade of 12 inches per 100 feet. Grade is excessive for heavy soil found here. Average heads of five to six cubic feet per second divided into two or four checks. Much care used in irrigating and only enough water added to reach lower end of checks without surface waste.

L. E. Tuttle Field. Seeded in 1907. Stand is among the best in area. Field has not been checked, irrigation being carried on by flooding from field ditches 200 feet apart. Portable canvas check gates are used to back up water in field ditches and are so placed that water spreads over a distance of about 200 feet at one time. Heads of four to seven cubic feet per second were divided into two ditches.

V. E. Breeze Field. Seeded in 1907. This field had been utilized for pasture for several seasons and stand was rather poor. Contour method used, checks ranging from three-fourths acre to two acres. Distribution of water over field uneven owing to poor grading. Average head of three cubic feet per second used and sometimes divided into three or more streams.

James Purdy Field. Seeded in 1912. Stand uneven and has been damaged in various spots by water standing on surface and poor drainage. Land in border checks 30 feet by 650 feet with average grade of about two inches per 100 feet. Heads of two or four cubic feet per second were used, one cubic foot per second usually being turned into each check. Despite the fact that small heads were permitted to run a long time over the land, it was difficult to place any appreciable amount of water below a depth of 12 to 15 inches.

W. B. Pine Field. Seeded in 1913. Stand good and land well prepared in border checks 30 feet by 400 feet, with average grade of about nine inches per 100 feet. Water was obtained from small pumping plant and an average flow of .3 to .45 cubic foot per second was turned into a single check. Moisture determinations showed that a more uniform distribution of water probably could be attained either by increasing the discharge from the well or by reducing the length of the checks.

George Cooper Field. Seeded in 1914. Stand comparatively good and land fairly well prepared in border checks 40 feet by 622 feet, with average grade of five inches per 100 feet. An average head of one and one-half cubic feet per second was turned into a single check.

H. J. Sykes Field. Seeded in 1913. Stand not uniform, there being small areas, especially at lower end of checks, where crop has been drowned. Land is in border checks 40 feet by 600 to 950 feet, with average grade of two and one-half inches per 100 feet. An average irrigation head of four to five cubic feet per second was divided among two or three checks. Difficulty was experienced in getting water to penetrate soil to any considerable depth.

Woodland Area.

Woodland is situated south of Cache Creek, in Yolo County, on the west side of Sacramento Valley. The mean annual rainfall at Davis, nine miles south, is 17.23 inches.[1] The water supply for irrigation is derived from Cache Creek by gravity and pumping, and by pumping from wells and from Willow Slough. Cache Creek forms

[1]Weather Bureau, Annual Summary for 1915. A record kept at Woodland by the Weather Bureau from 1873 to 1909 gave a mean of 17.73 inches.

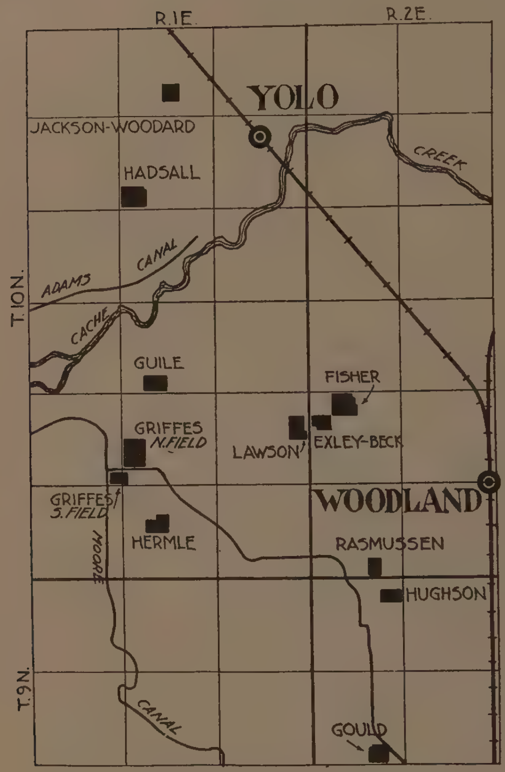

Fig. 14.—Map of Woodland area showing location of alfalfa fields under investigation, 1913 and 1914.

water are based directly on the quantities used rather than on the number of acres irrigated, irrigators seem more inclined to irrigate with reference to the immediate profits to be obtained for each crop than under any of the other gravity systems included in the investigation. In years of normal rainfall and for a limited number of years, fairly satisfactory crops of alfalfa are obtained around Woodland without irrigation, and when the market price of alfalfa is not high farmers frequently do without more than one or two waterings. The average total application in 1913 was 2.94 acre-feet per acre, the rainfall for that year having been 0.61 foot and the price of alfalfa relatively high. The average application per irrigation that year was 0.85 acre-foot per acre. In 1914, when the seasonal rainfall was 2.45 feet and the price of alfalfa was low, the average total application was only 1.80 acre-feet per acre, with the average application at single irrigations 0.99 acre-foot per acre. Thus the results in this area in 1913 show typical use in a year of great demand for water and of limited supply, together with a high average price for alfalfa, while in 1914 they show typical use in a season of ample water supply and minimum incentive to alfalfa production.

With equivalent total applications of water in the Woodland area, the yields generally were greater on the heavier soils than on the lighter soils, undoubtedly due to some extent to the greater moisture retentive capacity of the heavier soils. While the average yield of hay per acre from the irrigated fields under observation in 1914 was 6.75 tons, the average yield from three unirrigated fields in the same year was only 3.66 tons. In 1913 the duty of water was generally higher on the finer textured soils, and this held true for single irrigations in 1914, also.

Soil moisture determinations were made in the Woodland area in 1913 before and after one irrigation on the Lawson field and before and after three irrigations on the Jackson-Woodard field. In 1914 determinations were made at each cutting and before and after each irrigation on the Hughson, Beck, Griffes, Guile, and Jackson-Woodard fields. The average proportion of each application of water accounted for in the first six feet of soil was 36 per cent for the lighter soils, 44 per cent for the medium soils, and 56 per cent for the heavy soils, indicating in each case that the amounts of water applied were greater than could be held where probably most needed. On the other hand, the results indicated that in many cases, in spite of the excessive applications between cuttings, the moisture content present was inadequate at times, due to the too great interval between irrigations.

Hughson Field. (Fig. 15.) The soil of this field is classed as Yolo silt loam. Moisture determinations in 1914 were made from 12 borings before and after the first irrigation, from six borings after the second irrigation, and from six borings at the first, second and fifth cuttings. Taking the field as a whole, the percentage of moisture in the soil at the beginning of the season was well above the amount necessary to maintain growth, but fell below the wilting point in a portion of the upper six feet of soil by the time of the second cutting, and in the entire upper six feet by the time the third crop was two-thirds grown, when the first irrigation was given. This first irrigation brought the moisture content back to the desired point but it went down again below the wilting point by the time of the fourth cutting, after which the second irrigation was given. At the first irrigation a depth of 26.2 inches of water was applied. The greatest increase in moisture content due to this irrigation was between the sixth and the ninth foot in depth, as determined six days following the application, with the limit of penetration somewhere below 12 feet. Of the 26.2 inches applied at this first irrigation, only 10.23 acre-inches per acre, or 39 per cent, was accounted for in the upper 12 feet, with only 20 per cent of the total application accounted for in the upper six feet. In a general way the same results were indicated from the moisture determinations following the second irrigation. The fact that only about one-fifth of the water applied can be accounted for in the upper six feet of soil, and no more than two-fifths in the upper 12 feet of soil, is evidence that through too deep penetration at the upper ends of the checks, much water is wasted in attempting to irrigate the lower ends of the long checks—1,270 feet in this field.

Lawson Field. The soil in this field is classed as a silt loam. Moisture determinations were made from eight borings before and after the third irrigation in 1913, at which irrigation a depth of 7.32 inches

was applied. Of this, 2.56 acre-inches per acre, or 35 per cent, was found in the upper six feet, with two-fifths in the surface foot. An appreciable portion of the water applied undoubtedly penetrated below six feet in depth, but under the present conditions it is reasonable to assume that the greatest loss was due to evaporation during the extremely hot weather prevailing at the time. In general, the determinations indicate a lack of uniformity in water distribution.

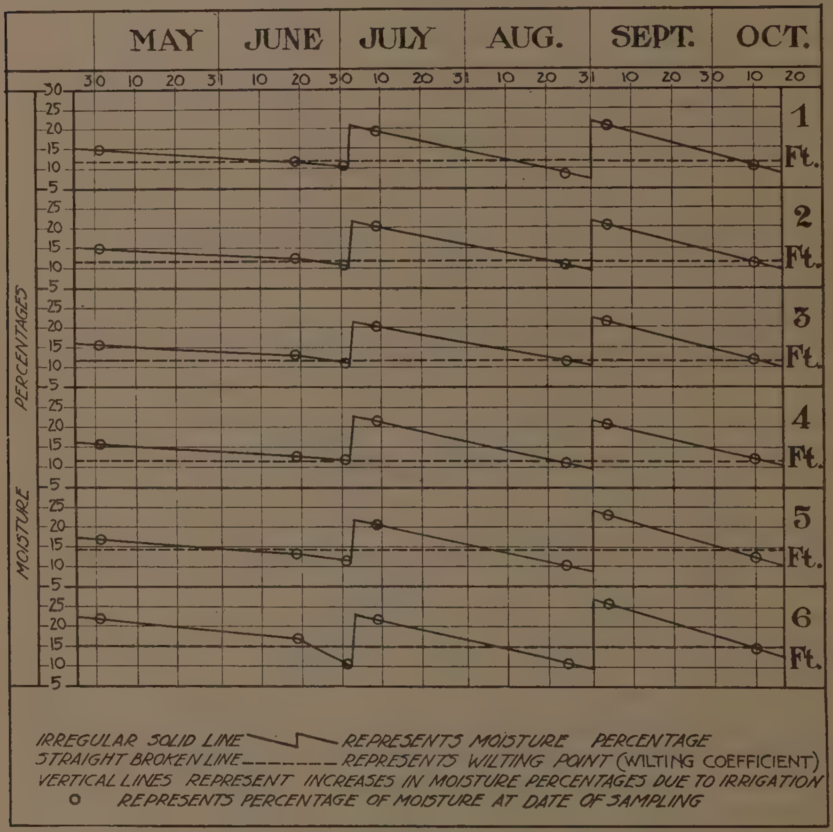

Fig. 15.—Diagram showing seasonal variation in soil moisture percentage, Hughson alfalfa field, Woodland, 1914.

Beck Field. The soil of this field is classed as Yolo loam. Soil moisture determinations were made from nine borings at each cutting and before and after each irrigation in 1914. Results, as platted in figure 16, indicate a very uniform decrease in moisture content of the soil from the beginning of the growing season until the first irrigation after the third cutting. The moisture present was above the wilting point throughout the upper six feet at the time of the first cutting, but was reduced to or below the wilting point by the second cutting,

and went below the wilting point in the upper four feet by the third cutting, although with appreciably no change at the fifth and sixth foot in depth. At the first irrigation a depth of 11.56 inches of water was applied, of which 5.04 acre-inches per acre, or 43 per cent, was retained in the upper six feet, one-fourth of this remaining in the surface foot. At the second irrigation a depth of 7.48 inches was applied, of which 3.34 acre-inches per acre, or 45 per cent, was retained in the upper six feet, with one-third of this remaining in the surface foot.

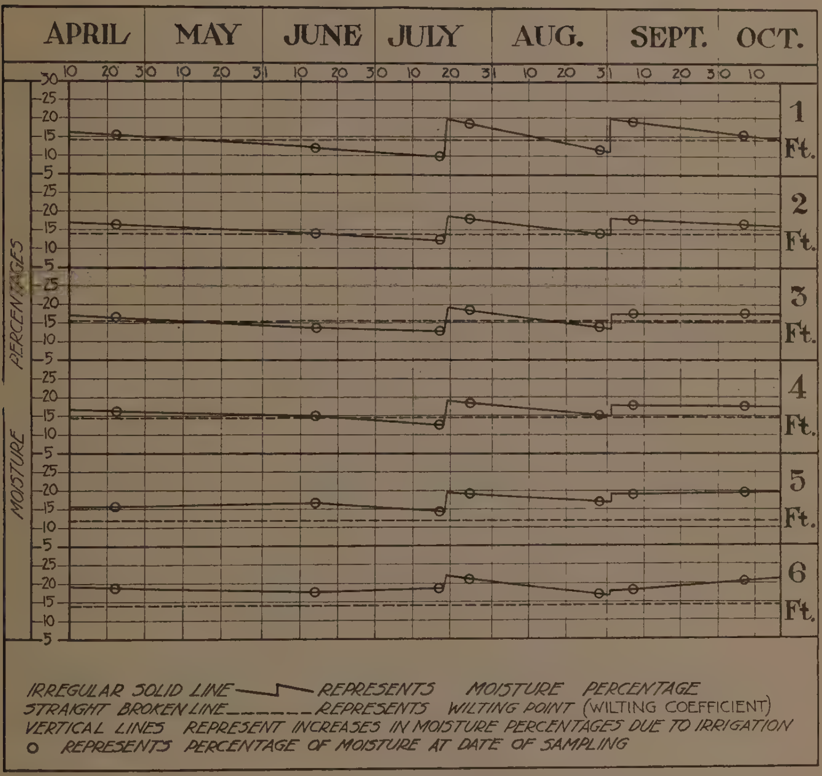

Fig. 16.—Diagram showing seasonal variation in soil moisture percentage, Beck alfalfa field, Woodland, 1914.

Griffes North Field. The soil in this field is classed as a silt loam. The field was irrigated twice in 1914 with approximately equal applications averaging 11.76 inches in depth. Moisture determinations were made from 18 holes before and after each irrigation and at each cutting except the fifth, when 12 holes were bored. At the first irrigation the upper six feet retained an average of 56 per cent of the amount applied, with relatively slight differences in the amount retained in each foot.

At the second irrigation 47 per cent of the quantity applied was retained, with the heaviest increase in the surface foot section. After the second irrigation the moisture decreased with the depth and indicated that less water went below six feet at the second irrigation than at the first. On the two plats into which the Griffes north field was divided, the north plat invariably showed a higher moisture content and produced a larger tonnage of hay. Taking the Griffes north field as a

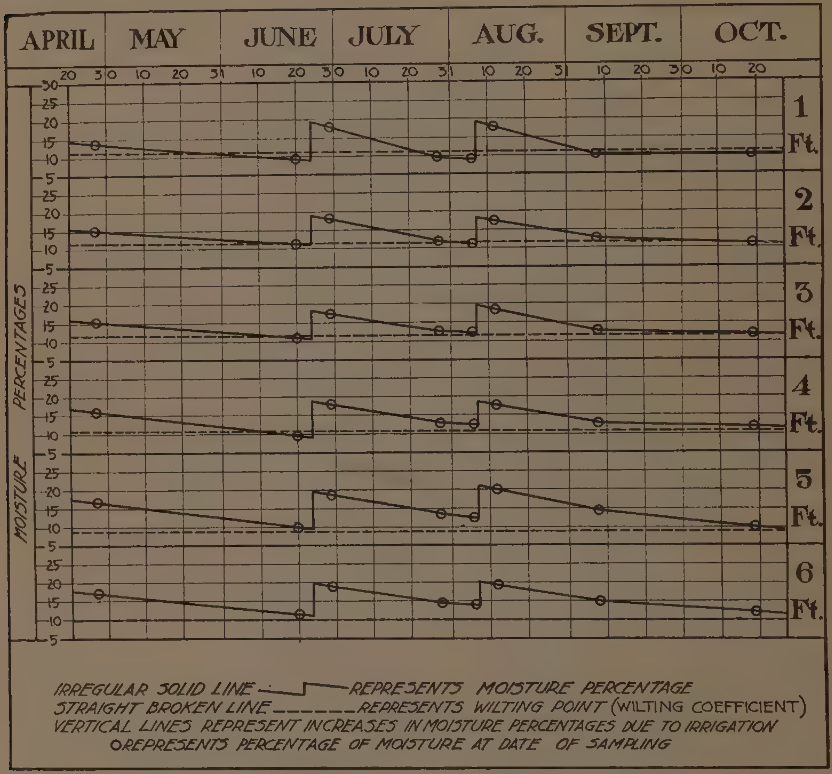

Fig. 17.—Diagram showing seasonal variation in soil moisture percentage, Griffes north field, Woodland, 1914.

whole the results in 1914, as platted in figure 17, indicate an abrupt decrease of the moisture content of the soil between cuttings and an abrupt increase caused by irrigation, the differences being more marked than in the case of any other fields in the Woodland area. This is accounted for by the coarse texture of the soil. While the upper strata of soil, in which the moisture was found to be below the wilting point just prior to irrigations, were amply replenished by watering, the determinations indicate that the lower stratum received more than necessary, showing that lighter irrigations would have proven more economical.

Guile Field. (Fig. 18.) The soil of this field is classed as Yolo clay loam. Moisture determinations were made from six borings before and after the two irrigations given in 1914, from three borings at the first cutting and six borings each at the fourth cutting and at the end of the season. At the first irrigation a depth of 7.28 inches was applied, of which 4.03 inches, or approximately 55 per cent, remained in the upper six feet, nearly one-half of this remaining in the surface foot. At the second irrigation a depth of 5.94 inches was given, of which

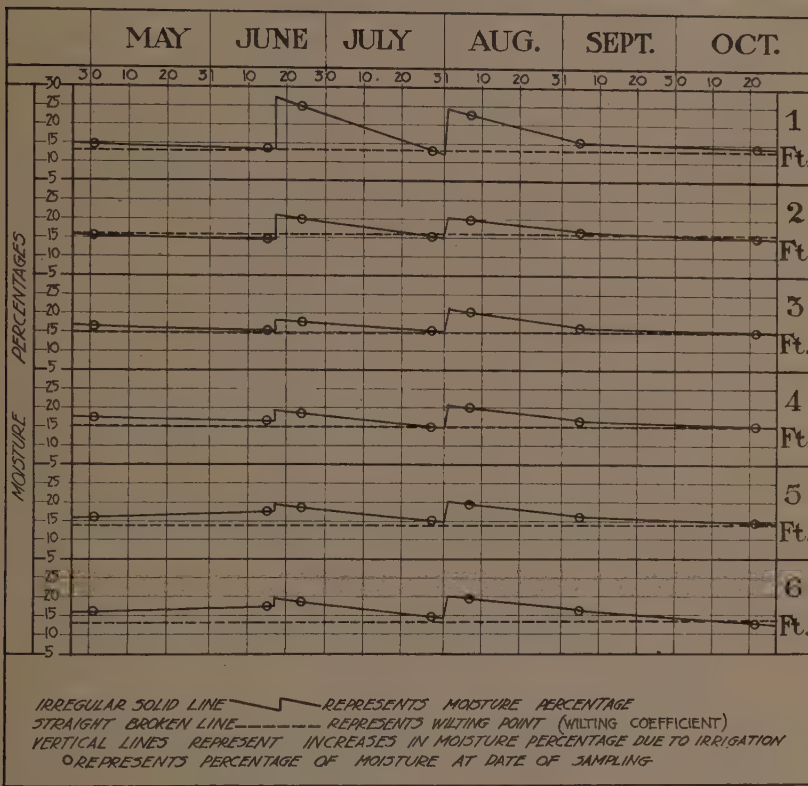

Fig. 18.—Diagram showing seasonal variation in soil moisture percentage, Guile alfalfa field, Woodland, 1914.

nearly 91 per cent was accounted for in the upper six feet, about one-third remaining in the surface foot. The relatively small quantities of water found below the surface foot or two confirmed field observations of the resistance offered by the soil of this field to the penetration of irrigation water. At the time of the first cutting the moisture content of the soil was so low, as shown by the diagram, that nowhere in the upper six feet was it much, if any, above the wilting point. And the same condition was approximated at the time of each subsequent cutting. Owing to the impermeability of this soil, heavy irrigations

were shown not to be practical. Perhaps no field studied in the Woodland area was found to be so dependent upon timely irrigation as was this one.

Jackson-Woodard Field. (Fig. 19.) The soil of this field is classed as Yolo clay loam. In 1913 moisture determinations on the north plat were made from six borings before and after the third irrigation, from ten before and after the fourth, from four before and after the fifth, and on the south plat from ten borings before and after each of the third, fourth, and fifth irrigations. The applications of water at the

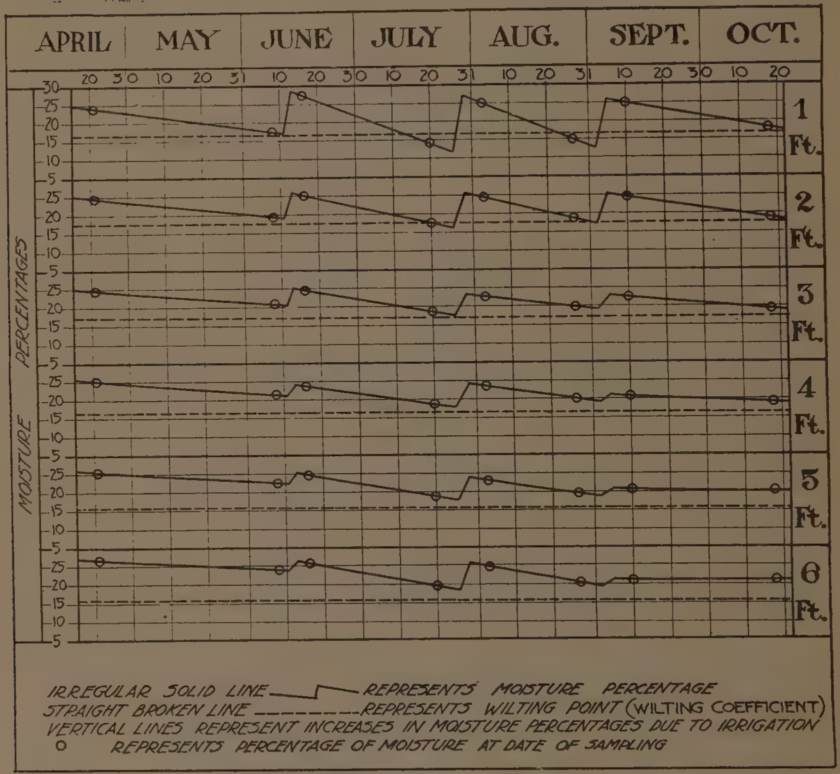

Fig. 19.—Diagram showing seasonal variation in soil moisture percentage, Jackson-Woodard alfalfa field, Woodland, 1914.

three irrigations were nearly equal, averaging 5.6 inches in depth on the north plat and 5.4 inches in depth on the south plat. The average depth of penetration of irrigation water on the north plat was found to be about four feet after the third irrigation and only two feet after the fourth and fifth irrigations, whereas in the south plat percolation extended to or exceeded six feet in each case. On the north plat the increases by irrigation were always small; on the south plat, however, 39 per cent was retained in the upper six feet at the third irrigation,

nearly 26 per cent at the fourth irrigation, and over 41 per cent at the fifth irrigation, the largest increases occurring in the surface two feet. In 1914 moisture determinations were made from six borings before and after each irrigation in each plat and at each cutting. The same differences in penetration of irrigation water found in 1913 were noted again. In addition to conserving a larger proportion of each irrigation, the south plat generally was found to contain a higher percentage of moisture than the north plat, especially in 1914, and the south plat in both years gave correspondingly larger yields of hay. As compared with the other fields in the Woodland area, there was a much higher percentage of moisture in the Jackson-Woodard field at the time of the first and second cuttings in 1914, with the average also remaining higher throughout the season. Prior to each irrigation, and more noticeably as the season advanced, the upper 12 to 18 inches of soil was found to be deficient in moisture, while the remainder of the six-foot section retained a uniformly fair moisture content. In both 1913 and 1914 the greatest increase in moisture resulting from irrigation took place at the lower ends of the checks, which varied in length from 340 feet to 575 feet. In 1914, for instance, when borings were made in three places in each check studied, the mean increase, expressed in acre-inches per acre, due to irrigation for the three irrigations was, respectively, 1.51 at the upper end, 2.44 at the middle, and 3.67 at the lower end in the north plat, and 3.44 at the upper end, 3.92 at the middle, and 4.74 at the lower end in the south plat. In other words, the soil did not absorb the water as rapidly as it was applied, and the result was an excess at the lower ends, where it penetrated in due time into the soil.

TABLE No. 13.

Summary of Results of Alfalfa Duty of Water Investigations, Woodland Area, 1913.

Name	Soil type	Area, acres	Number of irrigations	Total depth water applied, feet	Number of cuttings	Total yield, tons per acre
Geo. W. Hughson	Silt loam	19.54	3	4.40	5	9.12
H. J. N. Rasmussen	Silt loam	15.94	3	4.22	4	5.52
Sylvester Lawson	Silt loam	25.63	4	2.38	5	5.91
Wm. Exley	Silty clay loam	23.20	4	2.81	4	4.77
R. E. Fisher	Silty clay loam	37.71	3	1.30	5	3.46
Frank Hermle	Silt loam	23.88	3	3.12	5	6.69
Geo. O. Griffes (south field)	Fine sandy loam	16.65	4	3.07	5	7.49
Geo. O. Griffes (north field)	Silt loam	48.80	3	3.26	3	[1]2.55
D. B. Guile	Silty clay loam	28.21	4	2.14	4	4.42
Jackson & Woodard (north plat)	Clay loam	10.26	6	3.39	5	7.68
Jackson & Woodard (south plat)	Clay loam	9.49	6	3.08	5	8.51
Mrs. Nettie Hadsall	Silty clay loam	35.76	2	2.11	4	4.17
Averages				2.94		5.86
Averages, excluding young alfalfa				2.91		6.16

[1]Young alfalfa.

NOTE.—Rainfall November 1, 1912, to October 31, 1913, 0.61 foot

TABLE No. 14.

Summary of Results of Alfalfa Duty of Water Investigations, Woodland Area, 1914.

Name	Soil type	Area, acres	Number of irrigations	Total depth water applied, feet	Number of cuttings	Total yield, tons per acre
Wm. Gould	Silty clay loam	19.95	0	0.00	5	4.05
Geo. W. Hughson	Silt loam	19.54	2	2.91	5	6.96
H. J. N. Rasmussen	Silt loam	10.23	0	0.00	3	3.61
John Beck[1]	Yolo loam	23.20	2	1.59	5	7.28
R. E. Fisher (east plat)	Silty clay loam	16.21	0	0.00	3	3.33
R. E. Fisher (west plat)	Silty clay loam	21.50	3	2.03	5	4.92
Geo. O. Griffes (south field, east plat)	Fine sandy loam	5.48	1	1.41	5	6.12
Geo. O. Griffes (south field, west plat)	Fine sandy loam	11.17	1	1.00	5	5.56
Geo. O. Griffes (north field, north plat)	Silt loam	24.40	2	1.96	5	7.81
Geo. O. Griffes (north field, south plat)	Silt loam	24.40	2	1.96	5	7.40
D. B. Guile	Clay loam	28.21	2	1.14	4	4.28
Jackson & Woodard (north plat)	Clay loam	10.26	3	2.14	5	8.07
Jackson & Woodard (south plat)	Clay loam	9.49	3	1.88	5	9.11
Averages for irrigated fields				1.80		6.75

[1]The Exley tract in 1913.

NOTE.—Rainfall November 1, 1913, to October 31, 1914, 2.45 feet.

DESCRIPTIONS OF FIELDS IN THE WOODLAND AREA AND COMMENTS ON IRRIGATION CONDITIONS AND PRACTICES.

Wm. Gould Field. Seeded in 1910. Stand of alfalfa rather thin, with bare spots of considerable area. Checks 866 feet by 50 feet. Preparation of land good. Observations made on this tract only in 1914; it was not irrigated in 1914, owing to the low market price of alfalfa hay, but data were secured on yields in order to afford comparison with irrigated fields.

Geo. W. Hughson Field. Seeded in 1903. Stand of alfalfa good. Yields heavily but is being thinned out by gophers and by difficulty of getting water to lower ends of some checks. Checks 1,270 feet by 82 feet, with grade averaging 4.3 inches in 100 feet. Preparation of land fair, but checks much too long for porous silt-loam soil, for they require excessive applications of water at upper ends in order to wet lower ends, resulting in great waste of water. Small check-gates also contribute to this end. First three crops irrigated in 1913 and third and fifth in 1914, heads used varying from 12 to 22 cubic feet per second, divided among three to five checks. Second irrigation in 1914 covered only part of field. Difference in crop yields between 1913 and 1914 is attributable to lateness of first irrigation in 1914 and insufficiency of moisture later on.

H. J. N. Rasmussen Field. Seeded in 1910. Stand of alfalfa fair. Checks vary in length from 165 to 720 feet and in width from 40 to 90 feet. Grade averages 3.4 inches in 100 feet. Field divided into three sets of checks and general preparation good. Irrigating heads used in 1913, when the first three crops were irrigated, ranged from 14 to 22 cubic feet per second. In 1914, owing to low prices received for alfalfa hay, field not irrigated. Yield in 1913 reduced by grasshoppers.

Sylvester Lawson Field. Seeded in 1911. Stand very good over most of field, but there are several gravel streaks where poor. Checks vary in length from 740 to 1,080 feet and average 57 feet wide. Grade fairly uniform, averaging 4.6 inches in 100 feet. Land generally well prepared for irrigation. Observations made on this tract only in 1913, when heads used ranged from six to seventeen cubic feet per

second, only third crop being unirrigated. Soil moisture determinations at third irrigation indicated very unequal distribution of moisture. Two of crops damaged by grasshoppers.

Wm. Exley–John Beck Field. Seeded in 1906. Stand of alfalfa fair. Checks range from 375 to 1,290 feet in length, but width fairly uniform, averaging 73 feet. Grades range from zero to eight inches in 100 feet, averaging 3.1 inches. Preparation for irrigation fair. First, second, fourth, and fifth crops irrigated in 1913, with heads of nine to 14 cubic feet per second, and last two crops irrigated in 1914 with heads of 15 to 20 cubic feet per second, turned into two or three checks at a time. The great difference between yields of hay from this field in the two years studied due to ravages of grasshoppers, inability to cut the last crop because of rain, and inability to secure water when most needed in 1913, none of which conditions obtained in 1914.

R. E. Fisher Field. Seeded in 1907. This tract treated as single unit in 1913, but was divided into two plats in 1914. Stand generally good, but thinning out. Checks in east plat 320 to 630 feet long, in the west plat 700 feet long, and all average 58 feet wide, average grade being 1.9 inches in 100 feet. Field well prepared for irrigation, but ditches, originally made to take water from canal system, are too large for small heads, averaging 2.74 cubic feet per second in 1913 and 3.15 in 1914, secured from the pumping plant which now supplies the tract; checks also are too wide. Last three crops irrigated each year, but in 1914 only west plat was irrigated. Lower yield of hay in 1913 was due to failure to irrigate until after second cutting and to damage by grasshoppers.

Frank Hermle Field. Seeded in 1910. Stand excellent. Checks 630 to 640 feet long, average 65 feet in width, with average grade of 1.4 inches in 100 feet. Land well prepared for irrigation. First three crops irrigated in 1913, which was the only season in which observations were made, heads ranging from 13 to 19 cubic feet per second.

Geo. O. Griffes South Field. Seeded in 1912. This field comprises two distinct parts and in 1914 these were treated as separate units. Stand excellent. In the east plat checks are 800 feet long and in the west plat average 575 feet, all being 57 feet wide, with grade averaging 2.1 and 3.5 inches per 100 feet in east and west plats, respectively. Field well prepared for irrigation. In 1913 all crops except the third were irrigated, with heads of 11 to 15 cubic feet per second, and at the single irrigation between the third and fourth cuttings in 1914 the head averaged 20 cubic feet per second. Often the entire head was turned into a single check. Lower yields in 1914 were obviously due to the fact that only the fourth crop was irrigated, whereas all of the last three crops needed water.

Geo. O. Griffes North Field. Seeded in 1913. This field was divided into two plats for observational work in 1914. Stand of alfalfa one of the best in the area and field one of the most carefully prepared. Checks are all 810 feet long and 54 feet wide, with average grade of 1.4 inches in 100 feet in north plat and of 1.8 inches in south plat. All three crops were irrigated in 1913 with heads of 11 to 15 cubic feet per second, and in 1914 the third and fourth crops were irrigated with heads of 15 to 21 cubic feet per second, usually divided between two checks. The yields in the two seasons can not be compared owing to the fact that the alfalfa was in its first year in 1913.

D. B. Guile Field. Seeded in 1910. Stand of alfalfa fair. Checks average 1,275 feet in length, but vary in width from 45 to 120 feet, with average grade of 1.8 inches in 100 feet. Preparation for irrigation only fair. All four crops were irrigated in 1913 and last two in 1914, the heads of water averaging 12 cubic feet per second and usually were turned into single checks. It should be noted that, although only about one-half as much water was applied in 1914 as in 1913, the yield of hay was about the same in both years. This was accounted for by heavier rainfall and more timely irrigations in 1914.

Jackson–Woodard Field. Seeded in 1912. This field was treated as two units in 1913 and 1914. Stand of alfalfa excellent. In the north plat checks were 400 to 575 feet long, with grade averaging 2.2 inches in 100 feet, and in the south plat 340 to 520 feet, with average grade of 3.2 inches. All checks were about 40 feet wide. The checking system in this field was designed for a pumping plant and the general preparation was good. All crops were irrigated in 1913, including an irrigation after the fifth cutting, but in 1914 only the last three crops were irrigated. The pumping plant gave an average irrigating head of 3.78 cubic feet per second in 1913 and of 4.37 in 1914, in both cases being turned into one check at a time.

Mrs. Nettie Hadsall Field. Seeded in 1909. Stand only fair. Checks 970 to 1,105 feet long and from 45 to 60 feet wide, with average grade of 2.9 inches in 100 feet. Field generally well prepared for irrigation. Observations made only in 1913, in which year first and second crops were irrigated with heads of 13 to 16 cubic feet per second. This field is located under the Adams Canal and no water was available after early summer, whereas the tracts supplied by Moore Canal had a small amount for a much longer time, and this deficiency resulted in a low yield of hay.

Dixon Area.

Dixon is located in Solano County in the southwestern portion of Sacramento Valley. The nearest rainfall record is for Davis, eight miles northeast, where the mean is 17.23 inches.[1] At present no canal system serves the Dixon area, all irrigation water being secured by pumping from wells. In most cases the water is applied directly to the land without storage in farm reservoirs, although in the western part of the area several tracts are being irrigated from small pumping plants used in conjunction with storage. Some of the pumping plants are equipped with gas engines, but the majority have electric motors.[2] The soils of the area are mostly clay loams and clays of the Yolo and Capay series.[3]

Of the crops grown under irrigation, alfalfa occupies by far the largest acreage. In 1913 the average yield of six tracts of mature alfalfa was 6.76 tons per acre, distributed among five cuttings of 1.79, 1.61, 1.79, 1.35, and .22 tons per acre, respectively. The sudden drop in the average of the last cutting was due to the fact that the alfalfa on only two of these fields was cut five times, four crops being cut on three fields and three crops on the other.

The number of irrigations between cuttings varied in 1913 from one to four. Owing to the dryness of the season all first crops were irrigated, but in years of heavy rainfall one or even two crops may be grown without irrigation. The water-table was relatively low in 1913, and measurements of the discharges of 11 pumps showed all to be delivering below their rated capacities. Of two eight-inch pumps, the discharges were 29 and 36 per cent, respectively, below rated capacity; of three seven-inch pumps, the discharges were 12, 13, and 27 per cent

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[1]Weather Bureau, Annual Summary for 1915.

[2]Underground water conditions are discussed in U. S. Geol. Survey Water Supply Paper 375-A, Ground Water for Irrigation in the Sacramento Valley, California.

[3]U. S. Dept. Agr., Bureau of Soils, Reconnoissance Soil Survey of the Sacramento Valley, California.

below; of two six-inch pumps, 43 and 47 per cent below; and of four five-inch pumps, 54, 58, 66, and 71 per cent below, respectively. The expedient of lowering the pump several feet, which was tried by some owners, usually resulted in an increased flow.

Both square or rectangular and border checks are in use at Dixon, the former usually being made as nearly square and as nearly level as possible. Of the two, border checks probably are the more widely used, but on the heavier soils the square or rectangular checks are considered to give better results because it is possible, with such checks, to keep water standing on the land longer than with border checks, thus facilitating penetration. Square or rectangular checks at Dixon usually are about 100 feet square and border checks vary in length from 75 to 1,750 feet and in width from 30 to 40 feet, with a grade of three to five inches in 100 feet. Check gates are small wood or concrete structures, but often water is admitted to checks through cuts in the ditch banks. Metal dams or tappoons often are used for diverting water into the checks.

Seven typical fields were included in the investigation at Dixon in 1913 (Fig. 20), weirs generally being used for measuring the applications. Underground movement of irrigation water applied was traced only on the Wright field, and owing to difficulty in penetrating the heavy soil with a soil auger moisture determinations are available for the upper six feet of soil from only ten borings before and after the fourth irrigation, from four before and after the fifth, and from nine before and after the sixth. The mean moisture content of the upper six feet of soil over the whole tract was safely above the wilting point throughout the period of these determinations, although in many single instances the percentage fell below the wilting point prior to irrigations. This good moisture condition is attributed to the frequent light irrigations given, and the effect is well

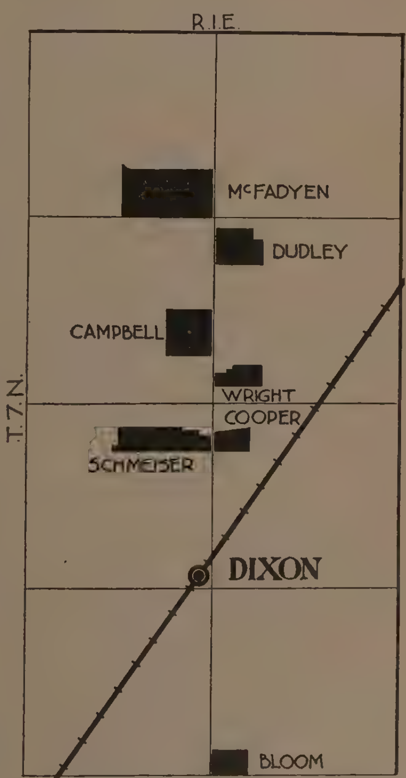

Fig. 20.—May of Dixon area showing location of alfalfa fields under investigation, 1913.

shown in the high yields of hay secured—9.97 tons per acre. The highest percentage of moisture was found before and after the fifth irrigation.

The distribution of the irrigation water applied throughout the upper six feet of soil at the fourth irrigation, when the moisture determinations were commenced, was very uniform, 49 per cent of the 5.06 inches in depth applied being accounted for. At the fifth irrigation, when a depth of 6.06 inches was given, only 31 per cent remained in the upper six feet of soil, over one-third of this remaining in the surface foot. The moisture found in the soil after the sixth irrigation decreased perceptibly with the depth, indicating that little passed below six feet, and that the principal part of the moisture not accounted for was utilized by the crop, or evaporated from the surface.

In addition to the borings made to a full depth of six feet, four additional borings before and after the fourth irrigation, six before and after the fifth, and three before and after the sixth irrigation were stopped by failure of the irrigation water to soften the hard soil to the full six feet. This again illustrated the desirability of having irrigations on this field sufficiently frequent to keep the soil moist constantly throughout the rooting zone of the plants.

TABLE No. 15.

Summary of Results of Alfalfa Duty of Water Investigations, Dixon Area, 1913.

Name	Soil type	Area, acres	Number of irrigations	Total depth water applied, feet	Number of cuttings	Total yield, tons per acre
J. R. Bloom	Clay loam	10.36	6	2.82	3	5.22
Mrs. Letitia Cooper	Clay loam	10.01	5	2.27	4	6.92
C. E. Schmeiser	Clay loam	36.20	8	3.06	4	5.61
D. W. Wright	Clay loam	12.10	8	3.15	4	9.97
M. D. Campbell	Clay loam	36.74	12	2.79	3	[1]1.72
E. D. Dudley	Silt loam	26.64	15	2.93	5	7.12
Harry McFadyen	Clay loam	74.12	15	3.43	5	5.72
Averages				2.92		6.04
Averages, excluding young alfalfa				2.94		6.76

[1]Young alfalfa.
NOTE.—Rainfall November 1, 1912, to October 31, 1913, 0.61 foot.

DESCRIPTIONS OF FIELDS IN DIXON AREA, AND COMMENTS ON IRRIGATION CONDITIONS AND PRACTICES.

J. R. Bloom Field. Seeded in 1890. Stand of alfalfa, which is one of the oldest in the area, still very good. Checks average 180 feet by 100 feet. Land generally is well prepared. First crop was irrigated once, second crop twice, and third crop three times, with head averaging 2.33 cubic feet per second. The relatively low yield of hay is attributable to lateness of beginning irrigation and to considerable damage done by alfalfa caterpillars (*Eurymus eurytheme*).

Mrs. Letitia Cooper Field. Seeded in 1904. Stand generally good. Checks roughly rectangular, from 55 to 195 feet long and averaging 52 feet wide. Checks mostly nearly level, but the longer ones have a grade of several inches in 100 feet.

General preparation for irrigation is good. Each crop was irrigated once with a head of 1.13 cubic feet per second, and a partial irrigation given after the fourth cutting. Water is purchased from a neighbor and the relatively low use probably is due to the fact that it was available only for a small part of the time.

C. E. Schmeiser Field. Seeded in 1907. Stand fair. Checks rectangular, about 110 feet long and 100 feet wide, and as a rule are mostly nearly level. Preparation for irrigation good. Each crop was irrigated twice with a head of 1.06 cubic feet per second.

D. W. Wright Field. Seeded in 1906. Stand very good. Checks rectangular, about 100 feet long and averaging 92 feet wide, and mostly nearly level. Land fairly well prepared for irrigation. First crop was irrigated once and each succeeding crop twice and extra irrigation was given after the fourth cutting. Average head of water .72 cubic foot per second.

M. D. Campbell Field. Seeded in 1912. Stand good. Field in border checks, 200 to 1,750 feet long and averaging 33 feet wide with average grade of three and one-half inches in 100 feet. General preparation for irrigation good. Each crop, including the pastured fourth crop, was irrigated three times with a head averaging 2.35 cubic feet per second.

E. D. Dudley Field. Seeded in 1912. Stand excellent. Border-check system followed, checks ranging from 85 to 570 feet long and averaging about 38 feet wide, with average grade of about six inches in 100 feet. Land, for the most part, is well prepared for irrigation. First crop was irrigated twice, second, third, and fourth crops three times each, and the last crop four times, with an average head of 1.94 cubic feet per second.

Harry McFadyen Field. Seeded in 1911. Stand of alfalfa good. Border checks, 60 to 940 feet long, average of 30 feet wide, with average grade of 3.6 inches in 100 feet. Land well prepared for irrigation. Each crop was irrigated three times with head averaging 2.44 cubic feet per second.

DISCUSSION OF RESULTS.

Comparison of Duty of Water and Yields of Alfalfa on 54 Sacramento Valley Farms with Results of Experiments at Davis.

As stated at the beginning of this bulletin, the purpose of the investigations herein reported was to obtain data that, taken in connection with the results of experiments in the duty of water for alfalfa at Davis, would give a basis for conclusions regarding the most satisfactory duty for this crop throughout Sacramento Valley. When a comparison is undertaken between the results of the investigations on the 54 Sacramento Valley farms studied in 1913 and 1914 and the results obtained at Davis from 1910 to 1915, it at once becomes clear that there is a wide variation, and that the results are not comparable unless full account is taken of the extreme differences in the conditions met. When the differences are analyzed, however, and the comparison is made between like or similar conditions, the results are not far apart. They are, in fact, sufficiently near agreement to establish the Davis results as applicable, in general, to the entire valley.

At Davis the amounts of water used were strictly under control, and, with the exception of the plat receiving a depth of 60 inches, single irrigations were, as a rule, not greater than the soil would retain, the soil

moisture determinations before and after irrigation showing that an average of 76.4 per cent of the water applied to plats which were given a depth of six inches in one irrigation was retained in the upper six feet of soil and that the plats given seven and one-half, nine, and 12 inches irrigation, making an average of nine and one-half inches per application, retained an average of 60.6 per cent in the upper six feet of soil and 97.7 per cent in the upper 12 feet. The soil of the experimental irrigation tract at Davis is chiefly a fine silt loam, relatively uniform, with no impervious stratum, and with the ground water level below the normal feeding zone of the plant roots. The upper two feet is very uniform, but the third to eighth feet are of fine, sandy loam, pocketed at irregular intervals with coarse sand or clay loam. While at Gridley the surface soil of the fields under observation in 1913 does not vary greatly from the soil at Davis, most of it is underlain with hardpan, and all of it contained free ground water at six feet or less from the surface. At Los Molinos, while the soil of some of the fields is comparable with that at Davis, being of silty or sandy loam and of relatively uniform depth for at least 12 feet from the surface, some fields have more clay and some are more gravelly than those at Davis. The normal rainfall at Red Bluff, which is the nearest point of observation to Los Molinos, is approximately nine inches greater than at Davis, and in the years 1913 and 1914 it was more than six inches above the average at Davis for the six years covered by the experiments there. An entirely different type of soil is found at Orland, all but one of the fields investigated having been made up largely of gravel. Here, also, water conditions differ considerably from those at Davis, a shortage of water in the late season in 1913 having made it necessary to eliminate one irrigation.

A very wide departure in soil type is encountered at Willows and, as indicated by the summaries of use on fields under investigation there, it was impossible to get enough water into the soil to satisfy the needs of the crop. While the soils at Woodland are generally comparable with those at Davis, paying for irrigation water on a quantity basis rather than on an acreage basis, as at Gridley, Los Molinos, Orland, and Willows, altered the Woodland practice materially. During the season of 1913 at Woodland, following a winter of low rainfall, the usual practice was to give at least three irrigations, and some farms received water six times, alfalfa bringing good prices that year and water therefore being applied plentifully. In 1914, however, following a winter of more than normal rainfall, and when the price of alfalfa had dropped to nearly one-third the figure obtainable in 1913, no irrigators watered more than three times and as a rule only two, with many not watering at all. Observations were made at Dixon during 1913 only. Water used there is obtained from pumping plants and use generally represents

what the various irrigators consider to be necessary. While in this regard conditions at Dixon are similar to those which governed during the experiments at Davis, at Dixon the soil is considerably heavier than at Davis, and takes water much less freely.

Gridley. Analyzing the results obtained at Gridley, it was found that a maximum yield of 9.38 tons was obtained from a field which received a total annual depth of irrigation water of 31.6 inches, but that the next nearest yield was only 7.28 tons per acre obtained on a field which received 34 inches of water for the season. Eight out of the fourteen fields studied at Gridley received greater annual depths of irrigation water than 34 inches, but on three of these the yield fell below five tons, on four below six tons per acre, and on seven below seven tons. In other words, after eliminating the single field that had the excessive yield of 9.38 tons per acre, it was found that the point beyond which it did not pay to add to the depths applied corresponds substantially with the points established in the Davis experiments, namely, between 30 and 36 inches. The seasonal rainfall at Gridley preceding the heaviest of these yields was 13.9 inches.

Los Molinos. Analyzing the results obtained at Los Molinos for the seasons 1913 and 1914, it is found that a maximum yield of 8.31 tons per acre was obtained with a total annual application of 47.4 inches, following an average rainfall for the two seasons of approximately 24.4 inches. To what extent, if at all, excessive use here reduced yields by soil leaching can only be conjectured. Seven of the 11 fields under observation received more irrigation water than the field of maximum yield, the maximum application being 84 acre-inches per acre. Of these seven fields, however, one yielded less than four and one-half tons per acre, four below six tons per acre, and six below seven tons per acre. At Los Molinos it is to be noted that both the maximum and the majority of applications were considerably in excess of the applications at Davis, but as pointed out in the discussion of soil moisture determinations in this area, the soils of the Los Molinos fields are highly permeable and the use of water was wasteful. Studies of the underground distribution of the irrigation water applied showed that beyond a doubt large quantities passed below a depth of six feet, single applications amounting, in numerous cases, to between 20 and 30 inches.

Orland. Averages for eight fields at Orland, where the soil is prevailingly gravelly, gave a maximum of 6.77 tons per acre with a total annual application of 24.6 inches after an average seasonal rainfall of 19.2 inches. The maximum yield at Orland was obtained on the field that received the least water, the yield from two of the seven remaining fields falling below five tons, and that from five falling below six tons. Of the whole eight fields water was applied in excess of 80 inches on

two fields, in excess of 55 inches on three fields, and in excess of 45 inches on five fields.

Willows. With complete results available for only one year and from only three fields at Willows, but with these results verified by special studies in 1915, it is evident that the results are in no way comparable with the results at Davis, this being due to the "tightness" of the soil of the Willows fields and the impossibility of getting irrigation water into it in amounts sufficient to satisfy the plants. A maximum yield of only 5.39 tons was obtained at Willows with an application of 23.6 inches in addition to the seasonal rainfall of approximately 28.7 inches for the preceding winter. Results at Willows indicate plainly that the soil-moisture needs of alfalfa, on the soils that hold moisture so tenaciously as do those at Willows, are in excess of the maximum applications found in 1914. Further, it is plain from the special studies in 1915 that to irrigate adequately the silty clay loams and the clay adobes of the Willows area, water must be applied frequently and in small quantities, and at no time following the winter rainfall must the soil be allowed to dry out. The amount of water used on these Tehama clay soils is sure to increase as improvement in their physical condition, due to cropping and cultivation, makes them more pervious to water.

Woodland. Averages for the 12 fields at Woodland, for which full records are available, show a maximum yield of 8.81 tons per acre with a use of water of 29.7 inches in addition to an average seasonal rainfall of 18.3 inches. Three fields, which received depths of 23.5, 33.1, and 43.7 inches, gave respective yields of 7.60, 7.87, and 8.04 tons per acre. Taking seven fields for which the yields were most nearly equal, the range of variation being slightly over two tons and the average yield being 6.93 tons per acre, the average use was found to be a depth of 30.7 inches. Thus, at Woodland it is found also that the usual maximum use, taking an average of one wet and one dry season, does not depart widely from that found most satisfactory at Davis; also that the maximum average yield for one field during the two years of record was obtained with slightly less than 30 inches.

Dixon. Here the largest yield in the single year of observation was 9.97 tons per acre with a total depth of irrigation of 37.7 inches, in addition to a seasonal rainfall of 7.31 inches. The average use for six fields, from which complete records are available, was 35.3 inches, or again in close agreement with the Davis experiments.

The allowance necessary to be made for difference in local soil conditions and irrigation practice is, it is believed, fully established by the comparisons made above. In general, as already indicated, the statement is justified that the six-year record for Davis is applicable

throughout the valley with the exception of on the very open soils such as those around Orland, and also with the exception of the silty clays and clay adobes found in these investigations in the neighborhood of Willows, but also existing elsewhere in considerable areas. The average for Willows indicates, as already pointed out, that total irrigations of less than 24 inches per season are insufficient for satisfactory yields, while the results at Orland indicate that applications averaging in excess of 48 inches per year, while sometimes difficult to overcome on the very gravelly soils, do not give corresponding increases in tonnage. The average use at Woodland, which was below that at either Dixon or Gridley, was plainly a result of the payment for irrigation water on a quantity rather than on a flat acreage basis. Finally, the average at Gridley illustrates what may be expected on the open loam soils underlaid with hardpan or ground water.

TABLE No. 16.

Summary of Results of Alfalfa Duty of Water Measurements on 54 Farms in Sacramento Valley, 1913 and 1914.

Name of area	Average rainfall, inches	Number of fields included	Areas covered by observations	Years	Average total depths of water applied, feet	Average total yields, tons per acre
Gridley	[1]22.24	14	284.22	1913	3.31	6.19
Los Molinos	[2]26.11	12	130.40	1913-14	5.15	6.01
Orland	19.23	7	214.52	1913-14	4.66	6.26
Willows	16.55	3	27.71	1914	1.83	4.82
Woodland	[3]17.23	12	295.07	1913-14	2.33	6.45
Dixon	[3]17.23	6	207.17	1913	2.94	6.76
Totals and averages	19.76	54	1,159.09		3.37	6.08

[1]Biggs record.
[2]Red Bluff record.
[3]Davis record.

Quantities of Water to Apply to Sacramento Valley Alfalfa Fields at Single Irrigations as Determined by the Capacity of the Different Soils to Retain Water.

Investigations of the gross and net duty of water made in the western states during the past two decades have demonstrated fully the need for carrying duty of water studies further than measuring the quantities of water applied. Therefore, in recent years, investigators have turned their attention to more or less precise methods of determining water requirements of crops under the various western soil and climatic conditions. The experiments on the duty of water for alfalfa conducted at Davis from 1910 to 1915 were intended to be as nearly as possible an application of these more or less precise methods to typical field conditions. When conducting the more general studies on typical farms throughout the Sacramento Valley, however, it was not possible, as already pointed out, to duplicate fully the methods followed at Davis.

Nevertheless, by making careful observations of the underground distribution of the irrigation water applied, a knowledge of what became of the irrigation water was substituted for a method of control that limited the applications to particular definite quantities.

At the outset of the investigations, one of the important practical questions presented was, how much irrigation water applied at one time, and added to that already present in the soil at the time of irrigation, would the various soils of Sacramento Valley retain? While no particular effort was made in the investigations to ascertain how much irrigation water the various soils encountered would hold during the actual process of irrigation[1], it was desired to ascertain how much would be retained after any surplus should pass on through the soil; or, in other words, how much of the water applied would be retained against gravity. As the amount retained would depend very largely upon the size of the soil particles, it was deemed best to have physical analyses made of the soil from a number of the fields under observation This was done by the division of Soil Technology of the college of agriculture of the University of California. Further: As the quantity of water soils will absorb and the rapidity with which it is absorbed depend quite largely on the compactness of the soil; and, also, in order to be able to determine what portion of the water applied in irrigation was retained by the soil, it was necessary to ascertain the volume weight of the soils "in place." This was done partly by standard laboratory methods, but chiefly by a special field method devised in the course of the investigations, and found to conform within satisfactory limits to other methods commonly used by investigators in more precise experiments.[2]

Reference to the amount of irrigation water that was retained by the soils of the various fields for which soil moisture determinations are available has been made in connection with the results obtained in the various areas. As shown there, the principal work in tracing the underground movement of the irrigation water applied was done on 15 fields—the Huartson and Williams fields at Gridley; the Wigno, Bundy, Hofhenke, and Geer fields at Los Molinos; the O'Hair field at Orland; the Purdy and Tuttle fields at Willows; the Griffes, Beck, Hughson, Guile, and Jackson-Woodard fields at Woodland; and the Wright field at Dixon. Results obtained in 1915 on the special experimental tract northeast of Willows are comparable with results on the 15 fields. The following summary arranges these fields in accordance with a general

[1]This was, however, indirectly ascertained through "pore space" determinations.

[2]The method followed consisted in weighing all of the soil taken from holes carefully bored with a two-inch posthole type soil auger and then ascertaining the volume of this soil as it was "in place" by the use of a thin rubber tube inserted in the hole and filled with a known quantity of water. This method was "checked" against the laboratory method by use of the Bowman soil compactor, the iron cylinder, and the paraffin methods as applied to soils in place, in a series of experiments conducted by Mr. O. W. Israelsen of this investigation and Professor Charles F. Shaw of the division of Soil Technology of the department of agriculture of the University of California.

soil classification and presents the essential data with reference to the amount of water retained in the upper six feet of soil on each field. With the possible exception of the Guile field at Woodland and the fields at Willows, the soil sampling indicated that the full capacity of the soil to retain water, assuming sufficient drainage to carry off the free water, was satisfied.

TABLE No. 17.

Summary of Number of Irrigations per Season, Average Depths of Water Applied at Each Irrigation, and Amounts of Water Retained in Upper Six Feet of Soil for Fifteen Typical Alfalfa Farms in Sacramento Valley, 1913-1914, and by Upper Five Feet of Soil on Willows Experimental Plat, 1915.

Class of soil and name of field	Location	Irrigations per season	Average depths of water applied per irrigation, inches	Water retained by upper 6 feet of soil	
				Acre-inches per acre	Per cent of amount applied
Silt loam soils with fine sandy loam subsoils—					
Wigno	Los Molinos	4	18.25	4.89	26.8
Griffes	Woodland	2	11.78	6.14	52.1
Averages			15.02	5.52	[1]36.8
Silt loam soils—					
Bundy	Los Molinos	4	12.30	4.03	32.5
Beck	Woodland	2	9.52	4.19	44.0
Hofhenke	Los Molinos	4	16.62	4.51	27.1
Averages			12.81	4.24	[1]33.1
Silt loam soils not included in preceding group—					
Hughson	Woodland	2	39.50	8.20	20.7
Huartson	Gridley	4	[2]7.20	4.19	58.1
Williams	Gridley	4	[2]5.88	[5]2.76	46.9
Clay loam soils—					
O'Hair	Orland	3	4.16	2.65	63.7
Geer	Los Molinos	4	19.67	4.50	22.9
Guile	Woodland	2	6.61	4.70	71.1
Jackson-Woodard	Woodland	3	8.04	3.33	41.4
Wright	Dixon	8	[3]5.44	2.31	42.4
Averages			8.78	3.50	[1]39.8
Clay soils—					
Purdy	Willows	4	5.06	1.48	29.2
Tuttle	Willows	4	[4]4.38	2.93	66.9
Averages			4.72	2.20	[1]46.8
Clay soils—					
Plats 3 and 4	Willows Experimental Tract	12	2.00	[6]0.54	27.0
Plats 6 and 7	Willows Experimental Tract	8	3.00	[6]1.07	35.7
Plats 11 and 12	Willows Experimental Tract	4	6.00	[6]1.57	26.2
Averages			3.67	1.06	[1]28.9

[1]Averages determined by giving percentages weights proportionate to the amount of water applied.
[2]Sampled only for last three irrigations.
[3]Sampled only for three irrigations.
[4]Sampled only for last two irrigations.
[5]Moisture determinations made to depth of only four feet.
[6]Moisture determinations made to depth of only five feet.

Examination of the above summary brings out the following facts that should be of practical interest to the irrigator:

1. Four times as much water was applied, on the average, to the silt loam soils with fine sandy loam subsoils as it was possible to apply, on the average, to the compact clay soils of the experimental tract at Willows, and more than three times as much as was applied to the clay soils of the Purdy and Tuttle fields at Willows.

2. Only about one-third of the water applied to the silt loam soils, as represented by five fields, was retained for the use of the alfalfa plants in the upper six feet of soil, where the principal root development is located.

3. In the case of none of the 15 fields under observation did the amount of water retained per irrigation in the upper six feet of soil exceed 8.20[1] acre-inches per acre, and in only two cases of the 15 did it exceed six acre-inches.

4. In only two cases out of ten in connection with the clay soils did the water that was absorbed by the upper six feet of soil reach four acre-inches per acre, in only three cases did it exceed three acre-inches per acre, and in four cases it was less than two acre-inches per acre.

5. The average quantities of water retained per acre-foot of soil per irrigation were 0.92 acre-inch for the silt loams with fine sandy subsoils, 0.71 acre-inch for the silt loams without fine sandy loam subsoils, 0.58 acre-inch for the clay loams, and 0.37 acre-inch for the clays, not including the experimental tract at Willows—in every case less than one acre-inch per acre-foot of soil.

6. The maximum average quantities of water retained by the upper six feet of soil per acre-foot per irrigation were 1.02 acre-inches for the silt loams with fine sandy loam subsoils, 0.75[2] acre-inch for the silt loams without fine sandy loam subsoils, 0.78 acre-inch for the clay loams, and 0.49 acre-inch for the clays.

7. Counting only the fields in which the full capacity of the soils to retain water against gravity was satisfied, *i. e.*, all of the fields having loam soils except the Guile field at Woodland, the average water retained per irrigation in the upper six feet of soil was 4.31 acre-inches per acre, or only 32.6 per cent of the average individual applications, and only 0.72 acre-inch per acre-foot of soil.

8. Assuming that in every case the surface foot of soil received at each irrigation sufficient water to satisfy its full capacity to retain water against gravity, it is found from the detailed data at hand that the average for the 18 fields, including the experimental tract at Willows, was 1.23 acre-inches per acre, and that the averages for the different soil types were 1.08 acre-inches per acre for the silt loams, 1.35 acre-inches per acre for the clay loams, and 1.35 acre-inches per acre for the clays. Therefore, in the case of the typical silt loam soils of Sacramento Valley, assuming one irrigation per cutting, single applications of irrigation water exceeding a depth of one to one and one-half inches per foot in depth of soil it is necessary to moisten accomplish no useful purpose; and while the typical clay loams and clays of Sacramento Valley, in their normal condition of moisture, will absorb and hold against gravity as much as one and one-fourth to one and three-fourths inches in depth of irrigation water per foot of soil it is necessary to moisten, that amount of water will not be absorbed by these soils unless it is applied very slowly.[3]

It seems perfectly evident from the figures given above that there is much ground for improvement in the matter of the quantity of water

[1]Clay loam strata at depths varying from eight to ten feet caused partial water logging in overlying soil, hence the figure 8.20 is unusually high. All of the water in this soil was not retained against gravity.

[2]Not counting the field on which 8.20 acre-inches per acre were retained because of abnormal conditions previously referred to.

[3]It is of interest here to note that with the surface foot of soil filled to its capacity to retain water against gravity, the percentages of the pore space of the soil filled were as follows: For the silty loam soils, from 37 to 55 and averaging 45.5; for the clay loam soils, from 51 to 71 and averaging 62.2; for the clay soils, from 57 to 74 and averaging 65.5; and for all of the fields combined, 54.5.

to apply to the alfalfa fields of Sacramento Valley at single irrigations. Had it been feasible to carry the soil moisture determinations to a greater depth than six feet, the extent of the waste resulting from the large single applications would be clearer. The data obtained are, however, sufficient to show clearly that the prevailing practice on Sacramento Valley alfalfa fields is to apply far more water at single irrigations than the more open soils have capacity to retain and than the more compact clay soils absorb under the methods of application followed.

A significant comparison can be made between the amounts of water retained by the soil in the case of the 15 typical Sacramento Valley alfalfa farms and the amounts retained in the case of six of the plats on the experimental tract at Davis, where the applications of water were under definite control. The average depth of water applied per irrigation to these six plats was 7.75 inches and the average quantity retained in the upper six feet of soil in the years 1913, 1914, and 1915 was 4.59 acre-inches per acre, or 66.8 per cent of the amount applied. On some of these plats, however, the borings for soil moisture determinations were made to a depth of 12 feet and it was found that within this depth practically all of the water applied was retained for the benefit of the plants. The average amount of water added by irrigation to the surface foot of soil in the Davis experiments was 1.45 acre-inches per acre. In other words, from the standpoint merely of the capacity of such deep loam soil as that at Davis to retain irrigation water against gravity, and assuming that the lower depths will "take up" as much water as the surface foot, the application once per cutting of one and one-half acre-inches of water per acre-foot of soil it is desired to moisten is not excessive.

Desirable Irrigation "Heads" for Sacramento Valley Alfalfa Fields.

In any investigation of the proper duty of water the size of the irrigation heads used and its relation to the type of soil irrigated, the method of irrigation followed, and the size and slope of the individual areas watered with a single head are always important. Fields may be evenly surfaced and levees perfectly made and proportioned and yet the result still will be excessive waste or inadequate absorption if the stream of water turned into each check is either too large or too small. The discussion as to what became of the water applied on a number of Sacramento Valley alfalfa fields, already presented, showed that where large quantities were applied to the open loam soils at single irrigations much of the water passed below the principal rooting zones of the alfalfa plants, and that the usual practice followed in irrigating the clay soils

failed to accomplish sufficient penetration by the water. The stabilizing of the irrigation heads used in Sacramento Valley, with direct reference to the size of checks and the character of the soil, is obviously one of the very important irrigation problems of the valley. Quite extensive experiments and observations will be necessary for furnishing a satisfactory basis for fully understanding this problem, but the collection of some information bearing on the question was accomplished during the investigations in 1913 and 1914. This information was obtained from twenty-five fields—three at Gridley, two at Los Molinos, five at Orland, two at Willows, nine at Woodland, three at Davis and one at Dixon. Five classes of soil were covered—gravelly loams, three fields; sandy loams, four fields; silt loams, nine fields; clay loams, six fields; and clays, five fields. Observations of the underground distribution of the water applied were made in connection with ten of the fields. The following summary lists the fields according to the soil classification made, with the fields within each group arranged according to the rates of application used expressed in cubic feet per second per acre.

TABLE No. 18.

Summary of Rates of Application of Water to Sacramento Valley Alfalfa Fields at Separate Irrigations, 1913-1915.

Soil type and field	Location	Year	Average length of checks, feet	Average width of checks, feet	Average slope of checks, inches in 100 feet	Number of irrigations represented	Average area of checks, acres	Average head turned into each check, cu. ft. sec. per acre	Average rate of application, cu. ft. per second	Average depth of water applied, feet
Gravelly loams—										
Holland	Orland	1914	150	50	Level	13	0.17	5.2	31.0	0.58
Lawton	Orland	1914	100	100	Level	13	0.23	5.0	22.0	0.74
Spence	Orland	1914	100	100	Level	10	0.23	3.7	16.2	0.56
Average									23.0	
Sandy loams—										
Griffes, south (west plat)	Woodland	1914	575	57	3.5	1	0.75	19.4	25.9	1.00
Griffes, south (east plat)	Woodland	1914	800	57	2.5	1	1.04	20.2	19.4	1.41
Griffes, north	Woodland	1914	810	54	1.0	1	1.00	10.3	10.3	0.96
Griffes, north	Woodland	1914	810	54	1.0	1	1.00	8.2	8.2	1.00
Griffes, north	Woodland	1913	810	54	1.0	1	1.00	8.0	8.0	0.92
Griffes, north	Woodland	1913	810	54	1.0	1	1.00	6.0	6.0	1.11
Griffes, north	Woodland	1913	810	54	1.0	1	1.00	4.8	4.8	1.23
Summers	Gridley	1913	465	55	3.5	4	0.59	2.7	4.6	0.56
Average									10.9	
Silt loams—										
University Farm, west half Field 3	Davis	1915	880	50	3.5	1	1.01	16.0	15.9	0.76
University Farm, west half Field 3	Davis	1914	880	50	3.5	1	1.01	15.1	15.0	0.84
Hofhenke	Los Molinos	1914	450	40	5.0	4	0.41	5.0	12.2	0.94
University Farm, west half Field 3	Davis	1915	880	50	3.5	1	1.01	10.9	10.8	1.48
University Farm, east half Field 3	Davis	1914	880	50	3.5	1	1.01	10.6	10.5	1.32
University Farm, west half Field 3	Davis	1914	880	50	3.5	1	1.01	10.0	9.9	1.17
University Farm, east half Field 3	Davis	1914	880	50	3.5	1	1.01	9.8	9.7	1.06
University Farm, Field 1B	Davis	1915	600	50	3.15	3	0.69	6.7	9.7	0.51
University Farm, east half Field 3	Davis	1915	880	50	3.5	1	1.01	9.7	9.6	1.70
Hermle	Woodland	1914	638	65	1.0	3	0.95	8.5	8.9	1.04
University Farm, east half Field 3	Davis	1914	880	50	3.5	1	1.01	8.8	8.7	2.78
University Farm, west half Field 3	Davis	1914	880	50	3.5	1	1.01	8.5	8.4	3.08
Hughson	Woodland	1914	1,270	82	3.5	1	2.40	15.3	6.4	2.00
McFarland	Gridley	1913	623	60	7.0	4	0.86	5.3	6.2	0.86
Hughson	Woodland	1914	1,270	82	3.5	1	2.40	9.6	4.0	2.28
Fisher	Woodland	1914	700	58	2.5	4	0.93	3.1	3.3	0.62
Huartson	Gridley	1913	610	65	2.5	4	0.91	2.4	2.6	0.66
Average									8.8	
Clay loams—										
Bratton	Gridley	1913	92	50	Level	4	0.11	1.9	17.3	0.96
Jackson-Woodard, south plat	Woodland	1914	449	40	3.5	3	0.41	4.4	10.7	0.63
Jackson-Woodard, north plat	Woodland	1914	478	40	2.5	3	0.44	4.3	9.8	0.71
Jackson-Woodard, south plat	Woodland	1913	449	40	3.5	6	0.41	3.8	9.2	0.51
Jackson-Woodard, north plat	Woodland	1913	478	40	2.5	6	0.44	3.8	8.6	0.56
Guile	Woodland	1914	1,275	94	2.0	1	2.78	13.3	4.8	0.49
Guile	Woodland	1913	1,275	94	2.0	4	2.78	12.0	4.3	0.54
Guile	Woodland	1914	1,275	104	2.0	1	3.05	12.5	4.1	0.61
O'Hair	Orland	1914	1,250	40	2.5	3	1.15	3.4	3.0	0.35
Wright	Dixon	1913	99	92	Level	8	0.21	0.2	1.0	0.39
Average									7.3	
Clays—										
Brantley	Orland	1914	150	150	Level	18	0.52	2.7	5.2	0.22
Goos	Willows	1915	600	40	12.0	7	0.55	2.5	4.5	0.23
Goos	Willows	1914	600	40	12.0	10	0.55	1.9	3.5	0.18
Chambers	Los Molinos	1914	561	50	2.5	6	0.64	1.0	1.6	0.24
Cooper	Willows	1915	622	40	5.0	7	0.57	0.7	1.2	0.22
Average									3.2	

It is evident from the above summary that the most desirable head of water to use on any given soil can not be determined adequately by comparing use on different fields, especially when the applications have not been entirely under control, with a view to determining the best rates to follow. The present general practice in Sacramento Valley, expressed in cubic feet per second per acre, is, however, satisfactorily indicated from the average figures obtained, namely, 23 for gravelly loams, 10.9 for sandy loams, 8.8 for silt loams, 7.3 for clay loams, and 3.2 for clays. The difficulty of irrigating porous soils with small heads, and of irrigating clay soils with large heads is well recognized among irrigators, even if the most satisfactory relationships have not been worked out in detail.

While a comparison of the rates of application on different fields as given above fails to disclose the best size of heads to use, a comparison of the relation between irrigation heads and depth of application on single fields makes it plain that in many cases the heads should be increased, or even better, that the area of checks should be reduced. This is made clear by the following summary which gives the average heads used and the depths of water applied for those cases in which more than one observation for a single field provides a basis of comparison:

TABLE No. 19.

Summary of Rates of Application of Water and of Depths Applied at Different Irrigations of Five Individual Fields.

Soil type and name of field	Rate of application, cu. ft. per sec. per acre	Depths of water applied, feet
Sandy loams—		
Griffes, south plat	25.9	1.00
Griffes, south plat	19.4	1.41
Griffes, north plat	10.3	0.96
Griffes, north plat	8.2	1.00
Griffes, north plat	8.0	0.92
Griffes, north plat	6.0	1.11
Griffes, north plat	4.8	1.23
Silt loams—		
University Farm, west half Field 3	15.9	0.76
University Farm, west half Field 3	15.0	0.84
University Farm, west half Field 3	10.8	1.48
University Farm, west half Field 3	9.9	1.17
University Farm, west half Field 3	8.4	3.08
University Farm, east half Field 3	10.5	1.32
University Farm, east half Field 3	9.7	1.06
University Farm, east half Field 3	9.6	1.70
University Farm, east half Field 2	8.7	2.78
Hughson	6.4	2.00
Hughson	4.0	2.28
Clay loams—		
Jackson-Woodard, south plat	10.7	0.63
Jackson-Woodard, south plat	9.2	0.51
Jackson-Woodard, north plat	9.8	0.71
Jackson-Woodard, north plat	8.6	0.56
Guile	4.8	0.49
Guile	4.3	0.54
Guile	4.1	0.61
Clays—		
Goos	4.5	0.23
Goos	3.5	0.18

It is seen from the above summary that in each instance for sandy loam and for silt loam the depth of water applied increased with a decrease in the rate of application, although in individual cases, and by a small margin, there are exceptions. As already pointed out in connection with the quantities of water the different Sacramento Valley soils will retain against gravity, the depths applied in single irrigations in such instances as the Griffes and Hughson fields—from 0.96 foot to 1.41 feet on the former, and as high as 2.28 feet on the latter—are plainly excessive, and the figures given above make it evident that, when compared to the size of the checks, the irrigation heads used on such fields were too small. This deficiency in the rate of application is even more plainly marked in the case of University Farm field No. 3, on which the depth of water applied per irrigation ranged from 0.76 foot to 3.08 feet and averaged 1.58 feet.

If the above figures seem to lack somewhat in conclusiveness, data obtained in a single experiment at Davis in 1915 fully support the conclusion reached above. In this experiment measurements were made of the amount of water required to cover a one-acre check having a slope of three and one-half inches per 100 feet when applied at different rates. The data obtained were as follows:

Rate of application, cubic feet per second per acre	Depth of water required, feet
4.6	2.75
10.1	1.86
13.5	1.16
15.3	0.84
17.8	0.69

Until the proper relation between irrigating heads and size of checks is satisfactorily worked out in Sacramento Valley soil, there is sure to be, there as well as elsewhere, much difference of opinion as to whether small checks and correspondingly small irrigation heads or large checks and correspondingly large irrigation heads should prevail in the irrigation of alfalfa. Those who favor large checks and large heads base their preference chiefly on the greater rapidity with which irrigation can be accomplished with large heads, and also on the assumed lesser cost of preparing the land for irrigation. As a rule, where large heads are available they are used, and in some cases, as pointed out in connection with the heavy soils, especially the "water tight" soils found in some portions of the Willows area, the heads were plainly larger than they should be. In the case of individual pumping plants, which rarely discharge more than one or two cubic feet per second, checks necessarily are small. That waste of land goes with the large field ditches necessary in carrying large heads, and also that extravagant notions of use, and

a greater waste when breaks occur with large heads, are sound arguments in favor of small heads, can not be doubted. Thoughtful consideration by irrigators and intelligent advice by public agencies in time will work out that relationship which best will serve both irrigators and the public. In the mean time, it is very clear that irrigators should bear in mind the fact that the irrigation head should not be a constant quantity, but should be varied where practicable, with the different soils found on nearly every farm.

Desirable Moisture Percentages for Alfalfa in Sacramento Valley Soils and the Effect of Variation in Soil Moisture on Rates of Alfalfa Growth.

In interpreting the large number of soil moisture determinations made at Davis and on Sacramento Valley alfalfa farms from 1913 to 1915, account has been taken of the moisture percentages found as related to the percentages at which the plants would wilt, and also of the effect of the variation in those percentages on the growth of the alfalfa. The percentages at which the plants wilt, or the "wilting coefficients," have been computed on the basis of the experiments of Messrs. Briggs and Shantz of the Bureau of Plant Industry of this department.[1] As indicated by these experiments, the wilting percentage may be stated to be the point below which moisture in the soil ceases to be available to the plants, or, at least, below which it is obtained only with great difficulty. Due largely to the difference in the size of the soil particles, plants will wilt in clay soils when there is still an amount of moisture that in sandy soils would be ample for all plant requirements. In interpreting the figures that have been obtained, therefore, in so far as they relate to the rates of growth of the alfalfa, it must be kept in mind that the percentage of moisture above the wilting point, or, in other words, the available moisture, has the most significance.

The summary below presents the essential soil moisture data found, expressed as percentages of the dry weight of the soil and ranged in order of alfalfa yields, for eight plats on the irrigation tract on the University Farm at Davis, for 1915; for six plats on the experimental field at Willows, for 1915; and for 11 Sacramento Valley farms for either 1913 or 1914, together with the soil types, the depths of irrigation water applied, and the total yields. In this summary the total and available moisture percentages are given, and also the range between mean maximum and mean minimum percentages.

[1] U. S. Dept. Agr., Bureau of Plant Industry Bulletin 230. The wilting percentages, or "wilting coefficients," for the Sacramento Valley soils are based on the "moisture equivalents" of those soils as determined in the laboratory of the division of Soil Technology of the department of agriculture of the University of California in the course of these investigations. It might be noted here that the moisture equivalents are the percentages of moisture retained in the soil after the soil has been subjected to a centrifugal force equal to 1,000 times the force of gravity.

TABLE No. 20.

Depths of Water Applied, Yields of Alfalfa, Percentages of Moisture Present, and Wilting Percentages for 8 Experimental Plats at Davis, 6 Experimental Plats at Willows, and 11 Sacramento Valley Alfalfa Farms, Arranged in Order of Yields.

Plats or field	Location	Soil	Depth of water applied, feet	Annual yields of alfalfa, tons per acre	Average per cent of total soil moisture present	Per cent of soil moisture necessary for particular soil to prevent wilting ("Wilting coefficient")	Average per cent of available moisture present	Range in per cent of available soil moisture
22, 25	Davis	Silt loam[1]	3.00	8.63	14.95	10.35	4.60	5.41
Jackson-Woodard	Woodland	Clay loam	2.01	8.59	21.46	16.45	5.01	4.14
Bundy	Los Molinos	Silt loam	4.10	8.39	20.35	15.12	5.23	4.58
21, 26	Davis	Silt loam[1]	2.50	8.32	16.91	10.35	6.56	6.11
23, 24	Davis	Silt loam	4.00	8.05	17.50	10.35	7.15	6.74
D	Davis	Silt loam[1]	2.00	7.96	16.50	10.35	6.15	5.83
Griffes	Woodland	Silt and fine sandy loam	1.96	7.69	14.59	10.67	3.92	5.49
Beck	Woodland	Silt loam	1.59	7.28	16.55	13.80	2.75	2.63
O'Hair	Orland	Clay loam	1.04	7.17	16.55	11.55	5.00	3.25
Hughson	Woodland	Silt loam	2.91	6.96	15.38	12.74	2.64	6.77
Wigno	Los Molinos	Silt and fine sandy loam	6.08	6.68	17.77	12.14	5.63	5.31
19, 28	Davis	Silt loam[1]	1.50	6.46	14.65	10.35	4.30	5.38
Geer	Los Molinos	Clay loam	6.56	6.06	19.93	14.44	5.49	3.84
Hofhenke	Los Molinos	Silt loam	5.55	5.75	17.83	10.80	7.03	4.34
31	Davis	Clay loam	5.00	5.55	27.38	16.59	10.79	7.74
3, 4	Willows	Clay	2.00	5.07	12.63	11.60	1.03	0.78
18, 29	Davis	Clay loam	1.00	4.84	20.39	16.59	3.80	5.67
6, 7	Willows	Clay	2.00	4.42	13.15	12.54	0.61	1.80
11, 12	Willows	Clay	2.00	4.29	11.84	12.38	—0.54	2.73
Guile	Woodland	Clay loam	1.14	4.28	16.99	14.41	2.58	3.40
Purdy	Willows	Clay	1.69	3.75	14.64	15.72	—1.08	1.61
17, 30	Davis	Clay loam	------	2.35	17.36	16.59	0.77	

[1]With fine sandy subsoil.

Average wilting percentages as given above: Silt loams with fine sandy subsoils, 10.65; other silt loams, 13.12; clay loams, 14.21; clays, 13.06.

Average per cents of available moisture present: With yields over 8 tons per acre, 5.71; with yields from 6 to 8 tons per acre, 4.48; with yields under 6 tons per acre due to excess of water, 8.91; with yields under 6 tons per acre due to deficiency of water, 1.02.

Obviously, it is impossible to disregard the numerous soil and climatic factors other than soil moisture that affected the yields of alfalfa and then to expect the yields and moisture percentages to be consistent throughout.[1] However, by grouping the yields above eight tons per

[1]The low yields on the Tehama clays at Willows suggested the desirability of a chemical analysis of the soil from the experimental plat there. Samples were accordingly taken at depths of 4 and 20 inches and submitted for analysis to Dr. C. B. Lipman, professor of soil chemistry and bacteriology, college of agriculture, University of California. The results of the analysis, together with the comments of Dr. Lipman, follow:

	Per cent at depth of 4 inches	Per cent at depth of 20 inches
Nitrogen	0.059	0.036
Phosphoric acid	0.11	0.12
Potash	0.53	0.62
Lime	0.63	0.74

"These analyses show that the great deficiency of the soil is in nitrogen, undoubtedly both available and total. There is an ample supply of potash, by all the standards which we use at the present time as criteria. There is a quantity of lime, which, for that type of soil, is low, though for ordinary soils would be quite ample. Therefore lime should be added to that soil in larger quantity for the sake of the physical condition, though chemically speaking, the above figures would appear to be adequate. The phosphoric acid content shows adequacy, provided the root systems of the plants can have at least three feet of soil to feed on. Otherwise phosphate fertilizers will have to be employed."

acre, from six tons to eight tons per acre, and below six tons per acre, it is possible to approximate the best or "optimum" percentage of available moisture over and above the amount necessary in each soil to prevent wilting. Assuming the yields over six tons per acre to have been produced on soil having at least as much as the "optimum" percentage of available moisture, the summary indicates that the "optimum" for Sacramento Valley conditions ranges between about three per cent and about seven per cent and averages about five per cent above the wilting percentage.

For the Hofhenke field at Los Molinos and plat 31 at Davis, on both of which an excess of irrigation water was applied, the average available percentage was 8.91, or well above the "optimum." On the other hand, the average percentage of available moisture on experimental plats 3, 4, 6, 7, 11, and 12 at Willows, plats 17 and 30 and 18 and 29 at Davis, the Guile field at Woodland, and the Purdy field at Willows, for which either the application or the absorption of irrigation water was plainly deficient, was only 1.02, or well below the "optimum."

The column in the summary giving the percentages of moisture that must be present in the various Sacramento Valley soils dealt with in order to prevent wilting, and also the averages for the various soil types as given at the foot of the summary, are believed to be of value because they indicate to Sacramento Valley irrigators not only the difference between the clay, or "heavy" soils and the loams and sandy soils as regards the amount of soil moisture needed to prevent wilting, but also that for all of the soils the wilting percentage is higher than farmers usually suppose. If one could assume an absolutely dry soil it might be convenient for irrigators to know that, as disclosed in the investigations reported herein, the amount of water necessary to supply the wilting percentage is approximately the equivalent of about one and two-thirds inches of rainfall per foot of depth of soil in which the crop is growing in the case of the silt loams with fine sandy loam subsoils, of about two inches in the case of the other silt loams, of about two and one-fourth inches in the case of the clay loam, and of two and three-fourths inches or more in the case of clays such as those found at Willows.[1]

In other words, with an absolutely dry silt loam soil eight feet deep the first 16 inches of irrigation water would no more than supply the amount of moisture necessary to keep deep-rooting plants from wilting; or expressed still differently, with such a soil wholly devoid of moisture, the equivalent of a rainfall of two inches for each one foot depth of

[1]The soil moisture studies in connection with the clay soils at Willows disclosed lower wilting percentages and lower capacities to absorb irrigation water than were to have been expected. It is not intended to discuss this technical phase of the subject in the present report, and conclusions for all Sacramento Valley clay soils can not and should not be drawn from the experience reported herein with the Tehama clays under investigation at Willows.

soil the crop utilizes would need to be supplied before the roots of the crop could begin to utilize the moisture. Fortunately an absolutely dry soil is rarely found in Sacramento Valley, even at the end of the summer season, and except in very dry years the soils of Sacramento Valley are not likely to begin the spring growing season with less soil moisture than the wilting percentage. Those having clay or other heavy soils, however, should not fail to take note of the very low available moisture percentages, or the absence of any available moisture whatever, and the resulting very low yields of alfalfa, indicated in the bottom six lines of the summary. The figures given should make it very plain that soils into which irrigation water percolates with difficulty should be watched very carefully at depths from four to six feet below the surface. The experience of the field investigators at Willows indicated that this care is especially necessary even early in the summer in order to insure that an adequate irrigation supply shall replace the moisture absorbed from the winter rainfall after that has been utilized.[1]

Seasonal Duty of Water on Sacramento Valley Alfalfa Farms.

For the purpose of showing what portion of the total irrigation water used annually by Sacramento Valley alfalfa growers is applied in each month of the irrigation season, the figures obtained for 1913 and 1914 have been averaged and the results given in Table No. 20. It is to be noted that the monthly use differs slightly in different sections. The greater rainfall at Los Molinos and Gridley results naturally in a later beginning of irrigation in the spring and an earlier ending in the fall. Besides, there was no water shortage at either Gridley or Los Molinos during the two years of the investigation. Irrigation at Orland ended earlier in 1913 than in 1914 because of shortage of water. At Woodland, as explained in the text, in 1913, which was a year of scant rainfall and high prices for alfalfa, in nearly each case irrigation began in March, whereas in 1914, a year of ample supply but of low returns on hay, it did not begin on any farm before June, in some cases not before July, and in two cases not before August, when a single irrigation for the season was applied. It might be added that the figures for both Gridley and Dixon covered the year 1913 only.[2]

[1]What is said in the text regarding desirable moisture percentages for Sacramento Valley soils growing alfalfa considers the matter only from the standpoint of the total annual yields of hay. It is obvious, however, that the annual yields are results of conditions that vary from day to day and from week to week. For instance, considering the moisture factor only, annual differences in yield were results of the daily and weekly differences due to daily and weekly variations in soil moisture. The data collected have been studied with reference to the effect of these changing moisture percentages on the seasonal rates of growth, but as no data were collected to indicate daily or even weekly variations in rates of growth, making it necessary to rely on average rates of growth between cuttings, such deductions as were suggested in the study have not seemed sufficiently conclusive to warrant their presentation. It is, however, possible to say that where the moisture percentage was found to fall below the wilting point there was also found a definite falling off in the rate of alfalfa growth.

[2]For seasonal duty on individual farms see Cal. State Dept. Engineering, Bul. No. 1, pp. 51-53.

TABLE No. 21.

Summary of Seasonal Duty of Water for Alfalfa on 62 Sacramento Valley Farms, 1913 and 1914.

	March, per cent	April, per cent	May, per cent	June, per cent	July, per cent	August, per cent	September, per cent	October, per cent
Gridley	----------	----------	28.42	20.86	20.22	18.43	12.07	----------
Los Molinos	----------	----------	18.57	19.23	24.10	18.71	18.29	1.10
Orland	6.46	5.46	23.69	18.46	18.55	15.07	9.46	2.85
Willows	----------	----------	19.17	21.83	16.17	27.83	15.00	----------
Woodland	14.86	----------	16.47	17.10	31.05	7.09	11.67	1.76
Dixon	4.14	10.43	14.28	16.00	20.00	13.57	14.87	6.71
Averages	5.18	1.75	20.21	18.76	23.40	15.34	13.61	1.75

NOTE.—Averages for entire valley figured from all farms and not from section averages.

Cost of Irrigating and Handling Alfalfa in Sacramento Valley in 1914.

Records were kept in 1914 of the cost of irrigating and handling alfalfa in the sections of Sacramento Valley where alfalfa duty of water determinations were being made. The items covered the cost of cutting, raking, shocking, stacking and baling. The average total cost of the first four of these items was $1.88 per ton. The cost of baling in Sacramento Valley ranged from $2 to $2.25 per ton. The prevailing prices of labor in Sacramento Valley were $2 to $2.50 per day per man and $1 per head for stock. The usual price for a man applying water was 25 cents per hour. The data gathered, averaged for the separate sections and for all of them taken together, are summarized in Table No. 21.

TABLE No. 22.

Cost of Irrigating and Handling Alfalfa, Sacramento Valley, 1914.

Area	Annual cost of irrigation per acre		Total cost of handling crop, per ton of hay						Total seasonal cost of handling crop, per acre	Total of all irrigation and handling costs, per acre
	Applying water, including cleaning of ditches where this is a factor	Water charges, or cost of pumping[1]	Cutting	Raking	Shocking	Stacking	Baling	Moving baled hay		
Woodland average	$0 92	$2 56	$0 28	$0 14	$0 20	$0 79	$2 14	$0 65	$12 79	$16 51
Los Molinos average	1 61	2 00	50	21	26	82	-------	-------	10 35	13 95
Orland average	2 14	2 00	53	23	34	89	-------	-------	11 46	15 59
Willows average	1 25	1 75	67	36	30	1 09	-------	-------	7 23	10 23
General average	$1 48	$2 08	$0 49	$0 23	$0 27	$0 89	-------	-------	$10 45	$14 07

[1]Do not include interest, depreciation, etc., or other similar "overhead" charges.

In comparing the costs for the different areas it should be borne in mind that the cost of water, the number of irrigations, and the number of crops cut were not the same in the different sections. For instance,

the highest cost per acre was at Woodland, where the charge for water was higher than elsewhere. The lowest cost was at Willows, where it was found more profitable to pasture the fields after two or three crops had been removed. The cost of applying water at Orland was about double that of other sections owing to the larger number of irrigations given between cuttings. The usual price received for alfalfa hay in 1914 was $4 per ton in the stack and $6.50 per ton baled.[1]

SUMMARY AND CONCLUSIONS.

1. This bulletin discusses observations of the duty of water made under the direction of the Office of Experiment Stations or the Office of Public Roads and Rural Engineering from 1910 to 1915, inclusive, at the California University Farm at Davis, on 54 Sacramento Valley alfalfa farms near Gridley, Los Molinos, Orland, Willows, Woodland, and Dixon, during 1913 and 1914, and on an experimental tract near Willows in 1915.

2. Soils, representative of extensive areas in Sacramento Valley, including the Madera, Gridley, Vina, Tehama, Elder, and Yolo series, were included in the investigations. The various fields represented classes of soil varying in texture from the gravelly loams of the Elder series to the clays of the Tehama series.

3. The water used on the alfalfa fields was measured by current meters or weirs and its underground distribution was ascertained by soil borings shortly before and shortly after irrigations and by about 11,000 soil moisture determinations.

4. Average annual depths of water applied were found to vary from 1.83 feet in the Willows area to 5.15 feet in the Los Molinos area, and on a single field the smallest annual application was 1.04 feet on a clay loam, as compared to 9.59 feet, on a gravelly loam, both of which were at Orland.

5. With the exception of the highly permeable Elder gravelly loams at Orland and the very impervious Tehama clays and clay loams at Willows, the results of the work, as a whole, are in agreement with the results of the six-year duty of water study at Davis. These have indicated that a depth of from 30 to 36 inches of water annually is the most desirable quantity of irrigation water to apply under general Sacramento Valley conditions. Total depths of less than 24 inches annually, exclusive of rainfall, are insufficient for satisfactory yields as indicated by the Willows work, while application of depths of 48 or more inches per year do not produce corresponding increases in alfalfa yields.

[1]For detailed costs on the individual farms see Cal. State Dept. Engineering Bul. No. 1, pp. 30-31.

6. Not counting the experimental plats at Davis or at Willows, moisture determinations were made chiefly on 15 fields, of which 13 were of silt loams or clay loams. In the case of all but one of these loam soils, for which one the full capacity of the soil to retain water was not satisfied, the average quantity of irrigation water retained per irrigation in the upper six feet of soil was equivalent to a depth of only 4.31 inches, or only 32.6 per cent of the average individual applications, and only 0.72 acre-inch per acre per foot in depth of the soil. Although the roots of alfalfa penetrate in these soils to a greater depth than six feet, it is plain that a considerable portion of the irrigation water went below the zone of greatest root activity and was largely or wholly wasted.

7. Considering the quantities of irrigation water retained in the upper six feet of soil for all of the fields for which soil moisture determinations were made, it is found that the average quantity retained in the lighter and more permeable soils was 0.92 acre-inch per acre for each foot in depth of soil, or the equivalent of five to six acre-inches per acre for six feet of soil, whereas the clay soils absorbed an average of only 0.37 acre-inch per each acre-foot of soil, or at the rate of only about two and one-quarter acre-inches for six acre-feet, due to their great imperviousness in their present condition. In the surface foot, however, the light soils retained an average of 1.04 acre-inches per acre-foot of soil as compared to 1.71 acre-inches per acre-foot held by the clay soils, this being in accordance with the well-known fact that clay soils, when thoroughly wetted, will hold much more soil water than soils of coarser or "lighter" texture.

8. Averaging the quantities of irrigation water retained by each field for which moisture determinations were made, it is found that the maximum quantities retained per acre-foot of soil per irrigation were 1.02 acre-inches for the silt loams with fine sandy subsoils, 0.75 acre-inch for the silt loams without fine sandy subsoils, 0.78 acre-inch for the clay loams, and 0.49 acre-inch for the clays.

9. Considering only the moisture determinations from the surface foot of soil of the 15 farms and the three Willows experimental plats for which such determinations were made—in each case the surface foot held its full capacity of irrigation water—it is plain that, in the case of the typical silt loam soils of Sacramento Valley, single applications of irrigation water exceeding depths of one to one and one-half inches per foot in depth of soil it is necessary to moisten accomplish no useful purpose. While the typical clay loams and clays of Sacramento Valley will retain against gravity in their normal growing condition as much as one and one-quarter to one and three-quarters acre-inches of irrigation water per acre-foot of soil, over and above the amount normally found in such soils under Sacramento Valley field

conditions, that amount of irrigation water will not be absorbed by these soils unless it is applied very slowly.

10. The wilting percentages or "wilting coefficients" for the Sacramento Valley soils under investigation ranges from 10.35 in the case of the silt loams of the experimental irrigation tract on the University Farm, at Davis, to 16.59 in the case of clay loam on the same tract. The average wilting percentages for the several types of soil under observation were 10.65 for the silt loams with fine sandy subsoils, 13.12 for the other silt loams, 14.21 for the clay loams, and 13.06 for the clays. The approximate quantities of water necessary to apply to thoroughly dry soils of the types listed to bring the moisture content up to the wilting points given are, in inches in depth per foot of soil, 1.5 for the silt loams with fine sandy subsoils, 2 for other silt loams, 2.3 for the clay loams, and 2.6 for the clays.

11. The optimum percentage of available soil moisture for Sacramento Valley alfalfa soils, over and above the percentage at which wilting occurs, seems to average between four and six per cent. This is equivalent to depths of from 0.6 to 0.9 inch of irrigation water per foot of soil for loam soils and of from 0.7 to 1.2 inches per foot of soil for the heavier clay loams and clays.

12. Alfalfa planted on very open and very impervious soils should be irrigated more than once between cuttings. This is necessary in the case of the open soils because of the inability of such soils to retain all of the moisture needed to mature a crop, and in the case of the impervious clay soils in order to accomplish deeper penetration of the irrigation water into them. In the case of the latter soils it is very desirable that the moisture supplied by winter rains shall be supplemented by irrigation water sufficiently early in the spring to prevent drying out. The frequent use by irrigators on such soils of a soil auger is to be urgently recommended, the investigations reported herein having demonstrated that penetration of irrigation water into the clay soils is very much less than irrigators usually realize.

13. Under the present general practice on the Sacramento Valley alfalfa farms under observation, the applications of irrigation water, expressed in cubic feet per second per acre, averaged 23 for gravelly loams, 10.9 for sandy loams, 8.8 for silt loams, 7.3 for clay loams, and 3.2 for clays. As checks seldom are as much as one acre in area, the actual irrigating heads usually were less than these figures. Where excessive quantities of irrigation water have been applied the reason very frequently has been the use of too small irrigating heads or of too large checks. Additional data are necessary to give a satisfactory basis for definite recommendation as to rates of application. It is already clear, however, that irrigating heads that are not large enough to enable

alfalfa checks to be watered evenly with six acre-inches of water per acre per irrigation are too small, and the remedy is either larger irrigating heads or smaller checks, preferably the latter, especially in the case of the smaller holdings.

14. Dimensions and grades of alfalfa checks vary somewhat in the six sections of Sacramento Valley studied. Some square and rectangular checks are used in each section but border or "strip" checks are most common, except on the gravelly soils at Orland, where the most satisfactory check probably is one about 100 feet square, containing a little under one-fourth acre, and with each check having direct access to a field lateral to do away with carrying water to one check over another. The border checks range from 30 to 120 feet in width and from 60 to 1,750 feet in length, the most usual width being from 30 to 50 feet and the most usual length from 400 to 700 feet. The grades of border checks range from 0.6 to 12 inches per 100 feet and average 3.6 inches per 100 feet.

15. Irrigation of alfalfa in Sacramento Valley is confined to the months March to October, inclusive, and in 1913 and 1914 it was confined to the months May to September, inclusive, at Gridley and Willows, and May to October, inclusive, at Los Molinos. Considering the entire six districts in which the investigations were made, the average percentage of the total annual use that was applied in each month of the irrigation seasons of 1913 and 1914 was as follows: March, 5.18; April, 1.75; May, 20.21; June, 18.76; July, 23.40; August, 15.34; September, 13.61; October, 1.75.

16. The general averages of the various items making up the cost of irrigating and handling alfalfa in Sacramento Valley in 1914 on 28 farms were as follows: Applying water, including cleaning of ditches, \$1.48 per acre; water charges, or cost of pumping, \$2.08 per acre; cutting, \$0.49 per ton; raking, \$0.23 per ton; shocking, \$0.27 per ton; stacking, \$0.89 per ton; total for handling crop, per acre, including cost of baling, \$10.45 per acre; total of all irrigation and handling costs, \$14.07 per acre.

PUBLICATIONS OF STATE DEPARTMENT OF ENGINEERING.

Report for the period, March 11, 1907, to November 30, 1908.

Second Biennial Report, December 1, 1908, to November 30, 1910.

Third Biennial Report, December 1, 1910, to November 30, 1912.

Fourth Biennial Report, December 1, 1912, to November 30, 1914.

Fifth Biennial Report, December 1, 1914, to November 30, 1916.

Bulletin No. 1, Progress Report of Cooperative Irrigation Investigations in California, December 1, 1912, to November 30, 1914.

Bulletin No. 2, Irrigation Districts in California, 1887-1915.

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[1]Since organization of the present State Department of Engineering in 1907. Numerous publications relating to work executed in cooperation between the state and the several branches of the Federal Government have been issued from time to time from the Government Printing Office at Washington. Application for these should be made to the Superintendent of Documents, Washington, D. C.